87-277

VB COOK

CONSULTING ENGINEERS

7560

STUDY OF

GEOLOGIC ISOLATION

OF

SOLIDIFIED WASTE RESIDUES

FOR

M. M. DILLON LIMITED

WILLOWDALE, ONTARIO

V. B. COOK CO. LIMITED

CONSULTING ENGINEERS

THUNDER BAY, ONTARIO

87-277 V. B. Cook Co. Ltd. - Study of Geologic Isolation of Solidified Waste Residues

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V.B. COOK CO. LIMITED
CONSULTING ENGINEERS

THUNDER BAY, ONTARIO P7C 4X8 P.O. BOX 936 740 S. SYNDICATE AVENUE PH. (807) 623-0461 TELEX 073-4537

November 16, 1987.

M. M. Dillon Limited,
47 Sheppard Avenue East,
P.O. Box 1850, Stn. A.,
WILLOWDALE, Ontario.
M2N 6H5.

Attention: Mr. Gary J. Komar, P. Eng.,
Environmental Engineering
and Science Division.

Dear Mr. Komar:

Re: OWMC Geologic Waste Isolation Study
Our Project No. 87-171-01.

We enclose herewith six copies of our report on the above study.

Capital and operating cost for work of this nature will be significantly influenced by site conditions and the actual physical nature of the material to be handled. The estimates provided herewith reflect the cost magnitudes to be expected, but are not suitable for exacting economic comparisons with other alternatives. We note in particular that no costs have been included for land or subsurface acquisitions, or for offsite transportation; we understand this to be consistent with the approach taken in costing other options.

Yours very truly,

V. B. COOK CO. LIMITED,

J. R. Morris, P. Eng.,
Project Supervisor.

JRM/nlk
Encl.

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EXECUTIVE SUMMARY

1. Geologic isolation of solidified waste residues by means of underground mined storage is technically feasible and environmentally advantageous.

2. Commercial and industrial storage in underground spaces is well established in past and current practice. Use is made of spaces resulting from past mining of mineral deposits, as well as purpose developed openings. Instances include the storage of industrial waste in salt mines, storage of hydrocarbon fluids and gases in excavated caverns, commercial warehousing in an abandoned limestone mine, and toxic metal residues in worked out areas of a gold mine. The widespread practice of backfilling metal mine openings with mine tailings, although undertaken primarily to provide ground support, also results in the storage of large quantities of material underground, reducing the surface impact.

3. The study area offers a full spectrum of geological settings in which to locate storage repositories, ranging from the granites and metamorphics of the Precambrian through the sediments and evaporite deposits of the Paleozoic. Precambrian rocks outcrop North of Lake Simcoe, being covered with increasing depth of Paleozoic strata to the southwest, with a depth to Precambrian surface of approximately 1500 metres in the Windsor and Port Burwell areas. The most obvious candidates for repository sites are the salt beds of the

Salina formation in the Goderich/ Windsor area, and the Precambrian which underlies the entire area. The Salina formation is attractive because of the extremely low permeability of the salt beds, affording excellent isolation of the wastes, and also because of the large excavated volumes available in the existing salt mines at Goderich and Windsor. The Precambrian is attractive as it underlies the entire industrialized area, in the northeast part of the region is at a convenient depth, and is overlain by thick shales which afford good isolation from the biosphere. Precambrian formations commonly offer competent rock with limited ground water. In the southeastern and south central portions of the study area the Precambrian is at substantial depth; more attractive targets may be found in Paleozoic limestones and shales.

4. A major factor in consideration of any underground waste storage system is disposal of the material excavated to create the storage spaces. Where storage is to be in an existing salt mine, disposal of the salt will obviously be attended to by the mine owner, with the storage spaces being a by-product. If development of a new salt mine for storage purposes was considered, presumably disposal of the salt would be arranged through parties presently in that market. Failure to arrange such marketing would seriously compromise

this option; the mined salt would itself become a major disposal problem.

If a non-salt mine were to be developed for storage purposes, markets for the excavated material would be established as part of the planning process. The most probable markets will be in the building aggregates and cement industries. The prices available in these markets may affect both the regional location of a storage site and the geological formation in which it would be located. Cement manufacturers require limestone and shale of certain qualities while aggregate producers can utilize granites as well as a variety of limestones and other Paleozoic rock types.

5. The form in which the waste is prepared for storage will have a significant affect on the cost of operating the storage facility. It is assumed for purposes of concept development and costing that the waste materials will be delivered in a form suitable for bulk handling, i.e. lumps or granules less than 150 mm in size.

Other forms, such as clay-like uncured residue from the solidification process, can be handled underground but may dictate substantial change from the methods proposed herein.

6. Both of the existing salt mines in Ontario are excavating at rates exceeding the projected space requirement for waste disposal. In addition, both mines have very substantial mined-out spaces presently available, such that either can be considered to have a potential service life of a century or more. Neither mine requires significant pumping so that, even in the case of suspension of mining activities, maintenance of the space would not be particularly onerous. The degree of maintenance work required to maintain access into the mined areas in the long term is uncertain; salt is a viscoelastic material, and tends to flow with time. This behaviour is accentuated with increasing depth.

New shaft and surface facilities would be required at either mine to handle the volume of material projected. A surface area of four hectares is estimated for the plant assuming an operation remote from the solidification plant with truck delivery of waste material.

A labour force of 31 persons is estimated for operation of the disposal facility.

During shaft sinking a modest amount (20,000 m^3 estimated) of excavated material will require disposal. Depending upon surface contours, some of this may be used for site grading. Following construction, the principal environmental impacts

will be the increased traffic and noise associated with trucking operation.

A period of 24 months is estimated for detailed engineering and construction. This does not include for site selection, permitting, and agreement on General Arrangements.

7. Construction of a new mine facility for waste storage offers the advantage of flexibility in location so as to minimize transportation costs and possibly to achieve waste treatment and disposal at a consolidated site. Underground excavations can be designed to optimize materials handling and long term stability. Siting approvals may be facilitated by locating the facility on a site such as an existing pit. More extensive surface facilities than in the case of an existing mine are required to dispose of excavated material, provide mine water treatment, and to provide mine ventilation supply and exhaust.

A surface requirement of 6.5 hectares is estimated for a stand-alone plant. A roster of 58 to 65 persons is estimated depending on repository arrangement.

The environmental impacts to be experienced will be those associated with a quarrying or gravel pit operation, principally the noise of trucks, loaders, and crushing and screening. A modest amount of noise will be created by the mine

ventilation fans, but with silencers this can be kept at a level below that of other noise on the site. Dust generation will be controlled by collectors and water sprays. If the excavation from the repository can be utilized as aggregate or cement feed replacing surface mined material, the repository can be considered as having a positive effect on land use in the area.

The time required from the commencement of detailed engineering to first emplacement of wastes is estimated at 30 months, excluding site selection, permitting, and agreement on General Arrangements.

Depending on the form of waste storage and the geometry of the repository, the subsurface area requirement will range from 1 to 5 hectares per year. As a subsurface repository area of over 1000 hectares is technically feasible, the potential life of the facility may be practically infinite.

8. The cost of geological and hydrological characterization of a new candidate site is estimated to be in the range of $1,000,000 to $5,000,000, depending on the target formation, proposed repository size, and geographic location. This does not include approval and permitting activities, or acquisition of surface or subsurface rights.

Characterization costs for an existing salt mine site will be substantially less due to the data base already available.

9. The integrity of natural containment systems is evidenced by storage over geologic time periods of hydrocarbon gases and by preservation of highly soluble salt deposits. The small breaks required in geologic barriers to provide access to the storage areas offer the least possible challenge to long-term containment technology. Considerable research is underway in connection with sealing of nuclear waste repositories which will be applicable to industrial waste storage facilities. No long-term containment activity is foreseen beyond monitoring of contaminant levels in adjacent geologic structures.

10. Costs of construction and operating the facility are site-specific. Probable costs are summarized in Table 1, assuming a repository depth of 500 m in the case of new construction. A possible credit for sale of excavated material is indicated in the case of a new mine, while a charge is included for use of mined space in an existing salt mine.

TABLE 1

GEOLOGIC WASTE ISOLATION - SUMMARY OF COST ESTIMATES

	Existing Salt Mine	New Mine	
		Vertical Layout	Horizontal Layout
Capital Costs			
Site Investigation	$ 2,500,000	$ 5,000,000	$ 5,000,000
Construction	22,470,000	40,230,000	38,410,000
Engineering	2,250,000	4,020,000	3,840,000
Contingency	2,470,000	4,420,000	4,230,000
Subtotal Construction	$27,190,000	$48,670,000	$46,480,000
Cost to Initial Disposal	$29,690,000	$53,670,000	$51,480,000
Annual Operating Costs[1]			
Mine Excavation Changes	1,340,000	---	---
Excavation	---	4,880,000	6,120,000[2]
Disposal	2,630,000	880,000	1,220,000
Credit for Rock Sales	---	(1,070,000)	(1,070,000)
Net Annual Operating Cost	$ 3,970,000	$ 4,690,000	$ 6,270,000
Closure Costs	$ 9,000,000[3]	$ 3,000,000	$ 3,000,000
Annual Monitoring Costs	$ 50,000	$ 50,000	50,000

1. At full rated capacity - 134,000 m^3/a.
2. Reduced disposal cost vs. salt mine reflects elimination of rehabilitation work and assignment of overheads to excavation.
3. High cost reflects effort to seal pre-existing mine shafts.

SECTION 1

INTRODUCTION

1.1 PURPOSE OF THE REPORT

This report will summarize the risk, impact, service, and cost factors involved in the underground disposal of solidified waste residues.

Historic and current practice in underground storage is briefly reviewed, and certain concepts are set out for more detailed examination in the report.

This study is based upon the use of conventional equipment and methods which have been proven elsewhere in the mining and construction industries, although their application to the storage of solidified waste residues may be unique.

1.2 TERMS OF REFERENCE

.1 Design and operating proposals shall be in accordance with OWMC philosophy:

- .1 Minimize risk to human health.
- .2 Minimize environmental impacts.
- .3 Maximize level of service.
- .4 Minimize financial cost.

.2 The geographic area to be considered in the study is that portion of Ontario lying between Lake Huron on the west, Oshawa on the east, and south of the latitude of Barrie.

.3 A comprehensive summary of excavation and disposal techniques will be provided. Detailed examination will be accorded to the options of disposal in existing salt mines, and development of a new mine(s) for the primary purpose of waste disposal.

.4 The principal materials to be stored will be slag and solidified ash from high temperature incineration and solidified residues from physical/ chemical treatment of industrial wastes. All residues except slag will be solidified prior to delivery to the underground storage. The materials will be substantially inert, and non-hazardous. Only normal industrial hygiene precautions will be required in their handling. The volume of these materials is estimated at 22,600 m^3/a initially increasing to 133,600 m^3/a in the tenth year, and to 135,300 m^3/a in year 20. Flexibility is required to meet these changes in disposal volume.

.5 Consideration of storage in existing mine workings will be limited to the salt mines existing in the Goderich and Windsor areas. This study will not involve field inspections of these facilities.

.6 Concepts for the development of a new storage mine will include locations in bedded (Paleozoic) and non-bedded (Precambrian) rocks, but will not be site specific. Siting considerations will be discussed.

.7 The study will identify:

.1 Surface facilities and land area required.

.2 Underground operations and equipment requirements.

.3 Transport methods between surface and underground.

.4 Health risks from surface water, groundwater, transportation, and mining/storage operations.

.5 Visual, noise, dust and odour impacts on the local environment.

.6 Economic effect on the local area.

.7 Service factors, ie. flexibility, reliability, and operations complexity.

.7 Cost estimates will be provided for capital construction, operations closure, and post-closure monitoring. Target accuracy will be ±35%.

All equipment purchases will be considered sales tax exempt.

SECTION 2

UNDERGROUND STORAGE SYSTEMS

2.1 HISTORICAL AND EXISTING EXAMPLES

.1 Underground space has been used for thousands of years for purposes ranging from storage to housing. Although no cases are known which precisely parallel the application proposed for OWMC, a review of past instances will provide a framework for the evaluation of future possibilities. A summary of some past and existing cases is given below:

.1 Limestone is mined by underground room and pillar methods in the Kansas City area for use as aggregates and asphalt mix. The limestone outcrops in the valley walls of the Missouri and Kansas rivers, and mine roadways enter horizontally from these valleys. The overlying shale and limestones are very tight, and despite the fact that the cover is only from 15 to 60 metres, the excavations are both dry and stable, permitting the use of the space for warehousing, light manufacturing, and offices.

.2 The Leyden lignite coal mine, fourteen miles northwest of Denver, Colorado is 200 to 250 metres below surface, overlain by shales and sandstones.

The mine operated from 1903 until 1950, with the mining resulting in over 4,000,000 cubic metres of storage space. After the completion of mining, test work showed that use of the facility for natural gas storage was feasible, and shaft seals were provided. The mine now provides storage at pressures up to 1,700 kPa.

.3 Underground caverns in Precambrian rock have been used in Scandinavia for the storage of petroleum liquids and gases, ammonia, potable water, and compressed air since the 1930's. These caverns are relatively shallow, normally designed so that hydrostatic pressure to surface is greater than the storage pressure of the product. Grouting is sometimes conducted to seal fractures in the rock. Some caverns are reported leakproof, while others do have leakage.

.4 Over eighty mine caverns have been used in the United States for storage of liquified petroleum gases. These are normally in sediments, predominantly shale, as compared to the igneous rocks used in Scandinavia. Caverns are normally at a depth of less than 150 metres. Leakages are usually stated to be negligible, although cases are quoted where caverns failed their testing with compressed air and were abandoned.

.5 The Wintershall mine in the Werra-Fulda basin of the Federal Republic of Germany mines potash at a depth of seven hundred metres. The potash seams are in the middle of a salt formation with a thickness of about three hundred metres, with clay, anhydrite, and shale above the salt. The formations are totally impervious.

The Herfa-Neurode section of the mine has been converted into an industrial waste storage. The wastes, which include heavy metal salts, cyanide compounds, pharmaceutical residues, and sludges containing organic compounds, are stored in palletized drums. There are restrictions on the type of wastes which will be accepted; liquid wastes, wastes with high vapour pressure, with poor thermal stability, and inflammability are not accepted for safety reasons. The facility operates as a warehouse, with full documentation of the nature and location of stored materials. Masonry walls are used to divide the mined space into individual rooms.

.6 Solution mining of caverns in evaporite formations has been widely used in North America to provide storage for hydrocarbons, and to provide disposal for chemical wastes, as in the Sarnia area. disposal. The caverns in Western Canada, are

typically at one thousand to two thousand metres depth, while those in Ontario are in the neighbourhood of five hundred metres deep.

.7 Arsenic dust resulting from the roasting of gold ores at Yellowknife, N.W.T., is stored underground in worked-out mine areas. These chambers are located within permafrost, and are closed off by bulkheads constructed of cemented mine fill.

.8 Backfilling of mining openings with waste material has long been used as a means of providing ground support and working access. In some instances in recent years, the storage aspect of backfilling has been significant from an environmental viewpoint. Filling has made use of a range of materials, from coarse broken rock to finely ground mill tailings. Natural sands and gravels have also been employed. Where low grade mine waste, or mill tailings, have been employed the filling material will be relatively high in heavy metals, and may provide worthwhile material for the study of long-term containment effects. Certain handling techniques may also be of interest in waste disposal:

.1 Hydraulic transport of mill tailings is widely used as an economical means of delivering backfill material to widely spread destinations, with great freedom in the geometry of the openings to be filled. Tailings are normally transported in a slurry with a density of about sixty percent solids by weight, and frequently have from five to fifteen percent Portland cement added for stabilization and for the creation of working floors. The relatively high water content requires that decant provisions be provided to remove the excess water. To ensure adequate drainage of the fill, and avoidance of subsequent liquifaction, limits are placed on the amount of slime material (smaller than forty-four microns) in the fill.

.2 Cemented rock fill is provided by mixing coarse broken rock with a cement slurry in proportions such that three to six percent cement is added. A variation of this system adds a sand fraction to the cement slurry. Various mixing techniques are used including regular concrete mixers, conveyor belts discharging into baffled chutes where the cement slurry is added, and the addition of a certain dosage of cement slurry to a truck-

load of rock fill with the mixing being accomplished by tumbling action as material is dumped. Despite these rather crude mixing techniques, strengths in excess of 10 MPA can be obtained.

.3 Pneumatic stowage has been used in coal mining, and to a limited degree in metal mining. The method is particularly suited to filling horizontal openings as waste material can be placed tight to the roof. Sized waste material (typically - 75 mm) is introduced through a rotary airlock feeder into a low pressure air line. Transport distance within the air line may exceed 100 m. Material is discharged at a significant velocity, resulting in compaction of the stowed material. Moisture is added to control dusting and optimize compaction.

.2 The following inferences may be drawn from past practice for design of waste disposal facilities:

.1 Satisfactory storage facilities have been constructed in geological strata similar to most of the rock types underlying Southern Ontario.

.2 Great depth of burial is not a prerequisite for hydrogeological integrity of the repository. However, where perpetual storage is desired with a minimum of ongoing monitoring and containment activity there are obvious advantages in placing wastes well below the surface aquifers, preferably below one or more aquitard formations.

.3 Current mine backfilling practices provide an area for study of emplacement techniques, and their long-term performance.

2.2 WASTE DISPOSAL FORMS

.1 The form in which waste is prepared for disposal affects the equipment and methods used for storage, as well as the layout of the repository. The broad options are as follows:

.1 Discrete packages, either containers on pallets or large precast units of solidified waste. This form would require handling by forklifts and/or trucks, would be relatively labour-intensive, and would result in a relatively low volume utilization in the repository because of the operating clearances required. The repository arrangement would be horizontal, with rooms of a relatively low height because of the stability limitations of

forklifts working on unprepared surfaces. Some use of this form is to be expected in the handling of special wastes which must be recoverable, regardless of the principal waste forms to be stored.

.2 Lump or granular materials, within the range of 6 mm to 150 mm in nominal dimension, can be handled as a bulk commodity using dump trucks, front end loaders and bulldozers, and conveyor belts. These handling methods are much less labour-intensive than those required for discrete packages. The repository layout could be either horizontal or vertical. (See Figures 6, 7.) A vertical arrangement of the storage spaces can provide greater storage volume per unit area of repository, reducing the amount of access development required. A vertical arrangement is amenable to gravity placement of wastes, reducing the stowage effort required.The space utilization would be superior to that in Point 1 because the granular material will totally fill the spaces available.

.3 Fine granular material, say from 0.1 to 6 mm in nominal size, could be handled by bulk mechanical transport or hydraulically. Increased dust problems can be expected with this form in the case of mechanical handling. Hydraulic transport

offers a non labour-intensive method of transport and placement, but the matter of decant water disposal must be addressed. A vertical arrangement is favoured in either case, although hydraulic placement can be effective in horizontal rooms.

.4 A combination of forms two and three above offers the possibility of in situ mixing at the disposal point, with a slurry fraction, containing Portland cement, and a granular fraction being combined at the point of discharge into the storage. It is possible in principle to design a materials mix which would not require water decantation. This approach would reduce the overall solidification effort as the intermediate stage of handling (and perhaps curing) material from a surface solidification plant would be avoided. This would also result in improved utilization of repository space, as interstitial space between granules would be largely occupied by the slurried fraction.

.5 Coarse granular material to 75 mm can be handled pneumatically. This would be an effective method of filling horizontal openings.

SECTION 3

STORAGE IN EXISTING SALT MINES

3.1 INTRODUCTION

Underground mining has been carried out in Southern Ontario for salt, gypsum, talc, and uranium. Only the salt mines in the Goderich and Windsor areas are to be considered in this study.

3.2 CANDIDATE SITES

.1 The Ojibway salt mine in Windsor mines at a depth of approximately 300 metres. Operations are by room and pillar method, with an average room height of six metres.

The mine is completely dry, although major aquifers occur in the overlying strata.

Solution mining from bore holes for salt brining and petroleum product storage has been carried out in the general area, although apparently in a different stratigraphic interval.

Space excavated to date exceeds 10,000,000 cubic metres, with a mining rate of 800,000 cubic metres per year.

.2 The Goderich salt mine is located on a gravel bar in the Maitland River in Goderich. Mine operations are beneath Lake Huron at a depth of approximately 520 metres. Mining is carried out in the A2 (lowest) member of the Salina formation. Other minable salt beds occur above the A2, which may be mined in future. Mining methods are room and pillar, with room dimensions 12 metres high by 12 metres wide by an indefinite length.

The mine is completely dry, although major aquifers occur in the overlying strata, particularly in the surficial deposits in the river mouth.

Salt brining wells have been operated in the area since 1866, and many wells are likely to exist, the locations of which are currently unknown. However, as all mine workings are beneath the lake remote from land-based wellsites, it is unlikely that problems would be encountered on this account. As well, brining operations are believed to be confined to beds considerably above the mine horizon.

Current excavation is at a rate of approximately 700,000 cubic metres per year, with a presently excavated space in excess of 10,000,000 cubic metres.

3.3 OPERATING CONCEPTS

In the absence of specific mine layout information it must be assumed that some interference is likely between the normal mining operations and the waste disposal activities. A key to minimizing conflict will be the minimizing of wheeled traffic, and to this end conveyors are suggested for transport of the solidified residues from the materials handling shaft to the storage area. Conveyors will be suspended from the roof to avoid interference with traffic and storage activities. At the discharge area the conveyor will unload either to a stockpile, or to the hopper of a pneumatic stower.

Room and pillar mine layouts have resulted in a checkerboard pattern of pillars with rooms, or excavated spaces, extending usually equi-dimensionally in two orthogonal directions. The conveyor can be aligned along a major accessway, with substantial lateral transport being required to move the material into the rooms at right angles. Depending upon which location was chosen, the height of the rooms are six metres (Ojibway) or twelve metres (Goderich). Stowage tight to the roof of the excavation is desired to assist long-term stability, to control ventilation flows, and to make maximum use of the storage system. Although the storage space may be considered a free by-product of the mining activity, expenses will be occurred in rehabilitation of the workings

(mainly scaling and rockbolting to guard against falls of ground), installation of power, water, and ventilation services, and extension of conveyor.

Use of conventional earth moving equipment such as trucks and bulldozers will achieve approximately 65 percent fill in a six metre height room or 80 to 85 percent fill in a twelve metre height room. This could be improved upon somewhat by use of low headroom coal mine type equipment, but at the cost of additional diesel-powered equipment underground and close exposure of personnel to dust producing activities and diesel fumes in areas which are difficult to ventilate.

It is proposed instead that pneumatic stowing be employed (see Appendix). Using this system in six metre high rooms, the total stowage would be accomplished pneumatically from the conveyor discharge. In the case of twelve metre high rooms, approximately half of the room height would be filled by mechanically spreading the discharge from the conveyors, advancing the fill with the conveyor to the limits of the storage area. From this outer limit the room would receive its final fill pneumatically in a retreating fashion, exactly as proposed for the six metre room heights. The pneumatic stower is visualized as a semi robotic machine, crawler mounted, being fed by an extensible shuttle conveyor from the main conveyor. Generation of dust would be suppressed by the addition of a certain amount of moisture

to the discharge stream, and diffusion of dust into the general mine atmosphere would be prevented by exhausting to a dust collector, from in front of the pneumatic blower unit, a volume of air well in excess of that required for stowage (see Figure 8).

With relatively modest robotic control the stower could operate around corners, and could stow cross rooms and adjacent rooms parallel to the belt without human entry to the space. This could reduce the amount of ground rehabilitation work by more than 50 percent.

Use of pneumatic stowage requires that material be free-flowing. Wet sticky material, such as uncured product from the solidification plant, would be unsuitable for this method.

Solidified residues at the periphery of the storage area will be in contact with the general mine operating area. Although the material will be non-hazardous, it will be advisable to place a barrier between the residues and the mine atmosphere. Rigid structures are not appropriate in salt mines, as creep of the salt in time results in destructive pressures. It is proposed that exterior surfaces of stored residues be covered with 1.0 m of salt screenings, available as a waste product from the underground crushing plant. No other confinement of residues will be provided.

Vertical transport into the mine will be provided by a conventional hoist. The hoist will handle a skip counterbalanced by a cage, with the skip being used to lower solidified residues to the storage level. The cage will be used for transport of men and materials. The skip will be loaded by means of a weight measuring flask at shaft collar level, and will discharge automatically to a surge bin at the bottom of the shaft.

A feeder will withdraw the material from the surge bin, loading it onto a conveyor belt. The conveyor belt will transport the material into the storage location, discharging either to stockpile for mechanical spreading or to the pneumatic stower for final filling and compaction of the storage rooms.

3.4 FACILITIES REQUIRED

The volume of material to be handled exceeds that which could be expected to be managed within the existing mine shaft facilities. In addition, special purpose facilities will be required which could not be constructed without seriously interfering with current mine operations. For the purposes of this study it is proposed that a separate site be established in the mine vicinity, accommodating the waste receiving facilities, bins and measuring flasks for transfer of materials to the shaft skips, and the associated office and service facilities.

Ventilation of the underground repository area is postulated as being taken from the principal mine ventilation circuit, with the exhaust from the repository area being passed through a dust collector to avoid any nuisance. The materials handling shaft will be air locked into the main mine workings, and a fan provided which will produce a down draft of fresh air in the shaft at approximately one metre per second. This air will supplement the general mine ventilation replacing air volumes used to ventilate the stowage area. Air heating facilities will be provided on surface to maintain shaft temperatures above freezing.

The materials handling shaft will be circular, approximately five metres in diameter, and concrete lined. The lining will be designed to hydrostatic criteria through the lowest aquifer after which the usual nominal lining design will be used. The shaft will be served by a friction hoist, as this multi-rope hoist design, under current regulations, permits design of a fully steel furnished shaft for lower maintenance.

As the bulk of the transport will be accomplished by conveyor or pneumatic stowage, very little equipment will be required underground. The anticipated mobile equipment roster is as follows: two supervisor's jeeps, service and maintenance truck, two front end loader/dozers (one spare), scaler/rockbolter, utility truck with boom. Non-mobile

equipment will include two pneumatic stowers (one spare), conveyor system, auxiliary fans, ducting, dust collector, and maintenance shop equipment. A maintenance shop facility will be provided near the shaft for all underground equipment. This shop will be equipped for routine maintenance welding, component change-out, and washdown and lubrication. Major mechanical rebuild of components will be done by commercial shops in the area.

3.5 IMPACTS

After completion of the construction phase no materials will be brought to surface from the storage facility. Environmental impact will thus be limited to the traffic effects of the trucking operation necessary to bring some 540 cubic metres per day (250 working days per year) of material to the repository. A modest amount of noise will also be generated by the material shaft ventilation supply fan, but this will not be noticeable over the traffic noises expected near any major thoroughfare.

The shaft headframe will be the major visual element, extending to a height of about 50 m, with a width of 12 m. Other buildings will be one or two stories high, of relatively small size.

A space requirement of approximately four hectares is estimated, assuming that storage of no more than two to three days' material will be required on surface.

The total payroll at the facility is estimated at 31 persons. As the operations will be highly mechanized this employment will be concentrated in the trades and administrative area. The classes of personnel required will be similar to those already employed in the mining operations in the area. The life of the facility is indefinite but may extend over several decades; this will be conducive to a stable labour force with strong social ties within the community.

3.6 RISKS

The most hazardous work involved in the storage operation will be the scaling and rockbolting of unused mining spaces. Some dust hazard may exist, and ventilation and dust control will be a major management objective. Other risks will include those associated with the use of mobile equipment.

The overall personnel hazards will be reduced by the use of remotely controlled and robotic equipment for ground rehabilitation operations as well as for materials stowage.

A lost-time accident frequency of no more than five cases per 1,000,000 manhours is anticipated from experience in current operation.

Climatic effects, i.e. wind, rain, and snow will not result in abnormal operating hazards, but have some potential for off-site dispersal of solidified residues. This will be mitigated by:

.1 Use of covered bins, rather than open piles, for residue storage.

.2 Enclosure of transfer points, such as truck dumps, and provision of dust collection.

.3 Site selection and grading to avoid flooding.

.4 Provision of drains and water impoundments to collect washdown or other water from material handling areas. Sediment from water impoundments will be added to residues for routine disposal. Treatment of discharge water is assumed to remove dissolved compounds.

Contamination of surface water sources from the disposal plant will be avoided by the above. As the underground workings are dry, no drainage contamination is expected from the disposal area.

Water is present in the existing shafts at Goderich, from groundwater leakage, condensation (in summer) and shaft sprinklers (required for timbered shafts), but is confined to the shaft area and should not be subject to contamination. Some water can also be expected in the residue handling shaft; this will be considered contaminated. This water can be used in dust suppression at the stowing area, where it will be absorbed in the residues. Any surplus will be pumped to surface and added to the site drainage collection system.

Contamination of groundwater during repository operations will not occur as flow is into the excavation. Flooding of the repository after closure must be considered probable in a geologic time frame, as no sealing system can be perfect and even salt beds have some permeability. Mitigation measures are discussed in Section 3.8, Closure and Monitoring.

3.7 SERVICE

Both the surface and underground facilities can be modified on reasonable notice to greatly increase the handling capacity. Major increases in hoisting capacity are much more difficult to achieve, and for this reason it is proposed that the hoisting facilities be sized to accommodate the projected operating rate of 134,000 m^3/year

on a single shift per day, 5 day week, basis. This will provide very comfortable operation with ample time for routine maintenance, and provides the ability to more than double the disposal rate if required in the future. During early years while disposal rate is less than designed, it will be possible to perform shaft inspection and maintenance work during the regular work week.

The plant will be composed of standard industrial equipment; we can identify no reliability problems related to the handling of solidified waste residues. The physical nature of the material must be defined prior to detailed system design. Systems designed for dry granular material, in particular the pneumatic stowing equipment, may not work if the product is damp and sticky. Ventilation and dust collection, a very significant plant item when handling a dry product, will be much less significant if the product is damp.

After an initial training period, operations are expected to follow a very smooth routine. Operations are simpler than conventional mining, where equipment placement and operating cycles are subject to interruption by blasting activities. Operations will be more predictable than on surface because of the controlled underground environment, not subject to climatic variations.

The pre-existing salt mine shafts may become liabilities because of their surface location, and possibly because the standard of construction through water bearing strata is less stringent than would be specified for repository accessways.

3.8 CLOSURE AND MONITORING

Two closure scenarios are possible:

.1 The waste storage facility is decommissioned while the mine continues to operate. The mine will remain dry, and the main closure activity will be covering of all waste surfaces with salt screenings. Concrete traffic barriers will be placed around the storage area to prevent inadvertent use of stored wastes for mine purposes.

Monitoring will consist of periodic inspections to confirm the integrity of the storage.

Upon eventual cessation of mining, sealing of shaft and long-term monitoring will be needed as outlined below.

.2 Mining operations cease before, or at the same time as, waste storage. All connections between the mine/repository and surface must be sealed.

Migration of contaminants out of the repository cannot occur until the repository is filled with water. After flooding, the rate of ion migration will be dependent upon the impermeability of the enclosing envelope, and the hydraulic gradients available to induce flow. It must be considered that over geological time periods the repository can be flooded by natural permeability through the salt beds. However, the major source of leakage into the repository is likely to be through the access shafts. Thus, shaft seals will be designed initially to prevent flow into the repository, with the long term purpose of preventing flow out of the repository.

Shaft sealing activities will begin with grouting of leakage zones in the shafts above the salt horizons. Grouting will be intended to seal permeable formations for several metres outside the shaft perimeters, as well as sealing leakages within the shaft liners themselves. The greater part of the effort is expected to be in the original mining shafts, which were not sunk with long term containment in mind.

After grouting, the shafts will be backfilled to the top of the salt formations. The backfilling will be done with granular material with a bentonite admixture. Bentonite swells when wet, creating a tight seal. It also absorbs heavy metal ions from solution, reducing

the rate of ion migration. Shaft furnishings will be removed during backfilling so as to avoid leaving channels through the backfill material.

On reaching competent non-salt formation the existing shaft lining will be broken out and a monolithic concrete plug placed, designed for full hydrostatic pressure at repository depth. After placement of the plug, grouting will be carried out in the surrounding rock to seal off any existing fractures.

Above this plug, removal of shaft furnishings and backfilling will continue. Similar concrete plugs may be required in the upper portion of the shaft to isolate aquifers from one another wherever it appears that such mixing would be undesirable.

Monitoring facilities must be installed with restraint, as the presence of drill holes or sampling pipes would constitute major breechs in the containment system. No penetrations through the lower shaft plug can be permitted, and installation of sampling openings in any plug above this must be carefully considered. It is proposed at this time that sample tubes be installed only to the top of the upper concrete plug. Even after sealing, it is believed that the shafts will be the most significant connections between surface and the repository, and monitoring of ground water within the

shafts will provide the best warning of contaminant migration. Monitoring holes elsewhere may be indicated by site specific geological knowledge such as the presence of solution cavities created by brining operations, but their depth of penetration must be subject to the same restraints as shaft sampling tubes.

3.9 COST ESTIMATE

.1 Site Investigation

Both candidate sites have been in existence as operating mines for some thirty years. Site investigation will consist primarily of compiling and reviewing technical information collected by the operators. Mine openings will be inspected to evaluate their stability, and suitability as containment structures.

Salt leaching operations have been carried out in both Windsor and Goderich areas. Available data will be compiled, but cannot be considered totally reliable. Seismic surveys will be required in the mine vicinity to define the presence or absence of solution cavities.

No significant program of deep test holes is anticipated.

An allowance of $2,500,000 for site investigations is proposed. This does not include senior program administration by OWMC or others. No provision is included for aquisition of surface or subsurface rights.

.2 Capital Costs

Estimates allow for shaft sinking to the depth of the Goderich salt mine, with a lateral connection of 500 m to the existing workings.

No allowances are included for permitting procedures, land acquisition, off-site trucking of shaft excavation, or delivery to site of solidified waste residues.

The site is assumed to abut an existing highway; no allowance is included for access roads.

Summary of Capital Cost Estimate

Materials Handling Shaft	$ 7,400,000
Headframe & Hoisting Facility	5,200,000
Underground Development & Rehabilitation	1,200,000
Underground Equipment	4,400,000
Change House	325,000
Shaft House	150,000

Shop and Warehouse	400,000
Offices	200,000
Ventilation Intake	100,000
Waste Residue Receiving	1,530,000
Water Treatment	250,000
Sewage Disposal	30,000
Water Supply	150,000
Site Allowances	410,000
Surface Mobile Equipment	550,000
Electrical Substation	175,000
Sub Total	$22,470,000
Design @ 10%	2,250,000
Sub Total	$24,720,000
Contingency @ 10%	2,470,000
ESTIMATED TOTAL CAPITAL COST	$27,190,000

.3 Annual Operating Costs

Estimates assume placement of waste residues by a combination of belt conveyor, mobile equipment, and pneumatic stowing. An allowance is included for purchase of underground storage space from the mine owner.

No allowance is included for senior off-site administration by OWMC or other bodies.

Costs are based on full operating rate of 134,000 m^3/a

Summary of Annual Operating Costs

Underground Labour	$ 520,000
Underground Equipment & Supplies	560,000
Site Service Labour	420,000
Administrative & Technical Staff	530,000
Energy	400,000
Site Supplies & Services	200,000
Sub Total	$2,630,000
Storage Space Charge @ $10/m³	1,340,000
ESTIMATED ANNUAL OPERATING COST	$3,970,000

.4 Closure

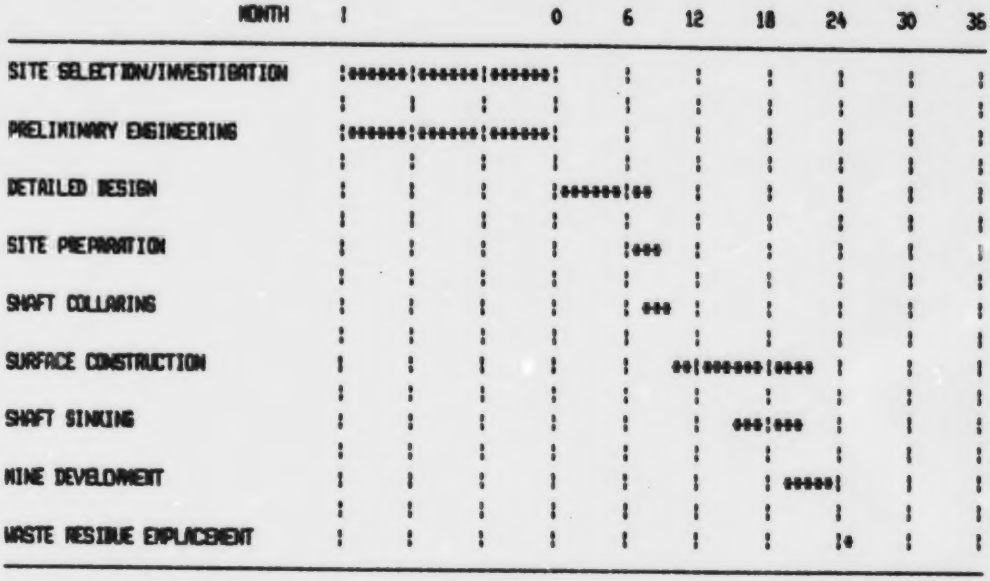
.5 Monitoring Costs

Monitoring will comprise periodic sampling through tubes placed in the shafts at closure. The work will not warrant full-time staff, and is envisaged as being performed on a contract basis.

Allow $50,000 per year

3.10 SCHEDULE

GEOLOGIC WASTE ISOLATION - DISPOSAL IN EXISTING SALT MINE



SECTION 4

STORAGE IN PURPOSE - DEVELOPED MINE FACILITIES

4.1 INTRODUCTION

The development of mine facilities for the disposal of solidified wastes offer certain advantages over the use of existing mine spaces. These include:

.1 The ability to design excavations to optimize materials handling and ground stability.

.2 The ability to locate access shafts to avoid hazards such as flooding, and to construct in a fashion which will simplify eventual sealing, e.g. pre-grouting to seal fractures is generally more effective than grouting after excavation.

.3 The ability to locate a facility to minimize transport distances.

.4 The ability to locate the facility on land which has already been zoned and utilized for industrial purposes, such as for instance a disused quarry or gravel pit area.

.5 The possibility of extending the subsurface area of the repository beneath Crown lands, such as parks or lakes, for economy in acquisition of rights.

Disadvantages of this concept include:

.1 Capital costs will be higher as facilities will be required for excavation.

.2 Arrangements must be made for disposal of the excavated material. It is assumed that such material would be saleable, either as salt in the case of a salt mine, or as construction materials in the case of a mine in non-salt formations. Such commercial disposal would be arranged through a third party.

.3 Operating costs will be higher by virtue of the excavation costs. This may be offset somewhat by the disposal value of the material.

4.2 SITING CONSIDERATIONS

There is a high probability of locating strata suitable for creation of a repository beneath any location in the study area. The site evaluation process will initially focus on the following aspects:

.1 Minimum transport cost for waste materials and disposal of excavated rock.

.2 Economy and expediency in land and subsurface acquisition and in approval processes.

Having defined the general areas of interest according to the above criteria, the following secondary criteria will be considered:

.1 Regional tectonics, i.e. faulting and earthquakes. Information currently at hand indicates that faulting in the study area is on a relatively large scale, with fault blocks of a dimension which are unlikely to rule out repository siting. Earthquake hazards, usually related to major regional faults, are low in this area.

.2 The presence of concentrations of oil and gas wells (see Figure 2). The presence of hydrocarbon fields does not rule an area out as a repository site, but obviously if the repository target stratum was above the hydrocarbon reservoir the wells would constitute obstacles to the development as well as possible leakage paths. Siting of the repository below the hydrocarbon reservoir would avoid interference except with surface facilities. Oil and gas drilling provides geological and hydrological data, and in this regard

may be positive in regard to repository evaluation. The presence of hydrocarbons, particularly natural gas, is de facto evidence of the long term containment capability of the overlying strata.

.3 Hydrology of the geological section, particularly the availability of one or more aquitard beds, both above and below the target formation.

.4 Availability of adequate thicknesses of rock which will yield both competent excavation conditions and a saleable byproduct.

.5 Availability of suitable areas of surface and sub-surface rights.

Localized investigation of potential repository sites will involve a combination of geophysical methods, primarily seismic, and test drilling. Considerable seismic and drill hole information is available from petroleum exploration which may provide a regional database. Further detailed work will be needed to localize a site. The temptation to drill great numbers of test holes into the repository must be restrained, as such holes would constitute potential leakage paths. Limited drilling will be mandatory to determine geology and hydrology. The target strata should have low permeability although higher permeability could be

accepted if confined above and below by aquitard beds. Groundwater is undesirable; any water present should ideally be potable. Piezometric level of the target formation will preferably be lower than that of overlying aquifers so that the prevailing flow gradient is downwards.

Any repository would be located below the water table, and would be isolated from ground surface by one or more aquitard formations. Surface hydrology will thus not be a concern except as it is affected by construction and site drainage. Minor amounts of mine drainage water can be expected; this will be recycled for industrial use (dust control) within the facility, and the balance, if any, will be treated to a high standard before discharge.

Repository depths of 1000 metres are under consideration for storage of nuclear wastes. This is well within the experience of current mine operations, and there is no general geotechnical reason why such depths should not be employed by OWMC. Overall project costs are expected to be only moderately sensitive to repository depth, with the marginal cost of increased depth expected to be in the range of $15,000 to $20,000 per vertical metre. This would include the material shaft, ventilation shaft, and allowance for increased size of hoisting equipment. A 1000 metre depth is not proposed as a target, but rather as a practical maximum.

Shallower depths are preferable where consistent with other siting criteria; a depth of 500-600m will be assumed in this report.

Precambrian rock offers perhaps the ultimate repository target. It is overlain by great thicknesses of shale, much of which is expected to be impervious. It has no commercial value, in situ, at the depths considered (except in the extremely unlikely case of discovery of significant mineral deposits) and so resources are not being sterilized. It can be considered homogenous for repository design purposes allowing substantial freedom in excavation arrangements. The Precambrian rocks are normally competent, requiring only nominal support during excavation. Disadvantages are that the rocks are frequently siliceous, giving rise to increased abrasion on operating equipment and to dusts which are hazardous to the health. The depth to the Precambrian basement is shown on Figure 1.

The Ordovician formations directly overlay the Precambrian in much of the area of interest (see Figures 3, 4). They consist largely of shales with some substantial thicknesses of limestone and dolomite. The shales are likely to provide useful aquitard structures above a repository, and may themselves provide repository sites, with the resulting excavation product being marketed to the cement industry. The limestones and dolomites could be marketed as cement plant feed or construction aggregates.

The base of the Silurian beds outcrops at the foot of the Niagara escarpment, and includes the limestones and dolomites currently developed in surface quarries. As these formations develop greater depth to the southwest they may provide repository sites.

4.3 OPERATING CONCEPTS

A room and pillar mine development system, similar to that discussed in the case of existing salt mines, is valid for the development of a storage facility. The room height might be increased, formation thickness permitting, so as to provide the requisite storage volume with less investment in mine development and conveying equipment. The plan arrangement will be mainly parallel rooms with a minimum of transverse connections so as to simplify waste containment and ventilation control (see Figure 7).

In Precambrian rock, or in limestones of considerable thickness, a vertical storage concept can be employed (see Figure 6). The repository would be developed from two mining levels 60 to 100 metres apart and the storage excavated in the form of cylindrical or prismoidal vertical silos between the levels. This arrangement requires less area development per unit of storage than a horizontal arrangement, reducing transport distances, the amount of roof which must be conditioned, and the amount of trans-

portation equipment. The arrangement naturally divides the activities into waste storage on the upper level and mine excavation from the lower level. Efficient long hole drilling methods can be used with the greater part of the drilling being done from the upper level. Remotely controlled load-haul-dump equipment would be used on the lower levels to pick up broken rock at the bottom of the silos; this method is currently in use in Canadian mines to allow recovery of ore from exposed areas without risk to operators. The major portion of the waste can be stowed by pure gravity methods, although it is expected that the upper mining level would be pneumatically stowed as with the horizontal concept so as to maximize space utilization and control ventilation circuits. The large amount of material which can be placed at a single point with this system opens possibilities in handling and solidification techniques. Conveyor systems could be very easily employed, possibly only having to utilize 3 or 4 discharge points in the course of a year. In situ solidification techniques may also be applicable, if suitable equipment were developed, since the equipment would not have to be highly mobile. This approach would minimize the handling of sticky mixed material, and would eliminate the need of any casting or crushing processes to prepare surface-solidified material in suitable form for transport underground.

Either truck or conveyor belt haulage could be employed for the volumes to be handled. Trucks will be the method of choice in the horizontal storage concept, providing the emplaced waste is suitable for wheeled traffic. As noted above, the vertical storage concept tends to favour a conveyor belt arrangement.

A double-entry system will be employed to provide ventilation supply and return passages. In the horizontal concept this will take the form of twin headings side-by-side along the main development corridors of the repository. Ventilation doors and overcasts will be used to direct the ventilation as required. In the vertical concept, the lower level will serve as the fresh air supply, with the upper, or waste handling, level serving as the exhaust. Connections between the two levels will be by means of slot raises driven for eventual excavation of the storage silos. Ventilation doors will be required to control short circuiting of air through open silos, and to direct the volumes where required.

For efficiency in shaft hoisting the excavated material will be crushed underground to approximately 150 mm. Further crushing may be carried out on surface to produce saleable products.

The repository site will be chosen for dryness, but it will be mandatory to provide mine pumping facilities. Depending upon the depth of the repository, pumping may be in the form of high-head submersible pumps or positive displacement pumps, in either case operating without a clarifier sump.

4.4 FACILITIES REQUIRED

A circular shaft of 5.5 metre diameter will be provided for vertical transport. The shaft in this case will be served by two friction hoists, one of which operates a counter-weighted cage for men and materials, with the other hoist operating two balanced skips which will raise the excavated rock and lower the solidified waste for storage. The hoists will be tower-mounted in the headframe.

Larger shops, change house, and office facilities will be required as compared to storage in existing mines so as to accommodate the extra personnel and equipment required for rock excavation. The waste receiving facilities will be very similar, including a weigh bridge, discharge hopper and conveyor belt to a storage bin adjacent to the shaft. Considerable complication will be added in the headframe area by the rock bin and conveyors. It is anticipated that the skips will dump rock into a small surge bin from which it will be conveyed to a large surface stockpile(s), either for sale or surface disposed.

As mine drainage must be accommodated, a mine water settling pond will be provided. This will be furnished with an impermeable plastic liner, and will serve as storage for process water (dust control) and fire protection supply. Surplus water, if any, will be passed through a water treatment plant before discharge to surface water ways.

Ventilation facilities must cater for the mine excavation as well as dust dispersion in the waste storage area. A ventilation volume of 100 cubic metres/sec. is used for estimating purposes.

Underground equipment is expected to include 2 service trucks, 2 development jumbos, 2 long hole drill rigs, 4 scooptrams, 4 haulage trucks, an explosive loading truck, 2 scalers/rock bolters, and 2 utility trucks. Fixed underground equipment will include the conveyors, crusher, pumps, local ventilation equipment, electrical distribution and communications, and the waste receiving and rock loading pockets.

4.5 IMPACTS

Traffic impacts in the area will be somewhat more than twice as great as in the case of storage in existing mines since the excavated material must be disposed of. In addition, it is expected that crushing and screening facilities, and

stockpiles, may be located on or adjacent to the site for the purposes of preparing the excavated rock in commercially marketable forms. The effect of such facilities could be mitigated by locating the facility on a site which has previously experienced similar use.

The visual impact of the facility will be that of a small industrial site, with the headframe tower rising approximately 50 metres with a cross-section of 12 m x 12 m. The balance of the buildings will be generally 2 stories high, and will be architecturally treated so as to blend as well as possible with the local landscape.

The mine exhaust air will cool adiabatically when rising from depth and condensation may occur which will show a light fog plume during certain seasons of the year. A light cloud of blasting smoke will occur 3 to 4 times per day during shaft sinking, and once daily during normal operation. Duration of the clouds will be about 15 minutes. The smoke has a light odour which disperses after a few hundred metres.

Mine water discharge is expected to be very small and may in fact be nonexistent. Significant water sources would be expected in the shaft where it penetrated aquifers. Perfectly tight sealing of shaft linings is expensive and time consuming and it is common to accept a few liters per

minute of leakage; greater than normal effort will be taken in this case, to minimize operating and final closure problems.

The facility will offer stable long term employment, with a high degree of mechanization to ease the arduous portions of the mining work. The labour force will be made up primarily of equipment operators, tradesmen, and administrative personnel. Many of these may come from construction and pit operations pre-existing in the area. Total personnel are estimated at 65 for a horizontal storage arrangement, or 58 for a vertical arrangement.

4.6 RISKS

Occupational hazards in underground work will be similar to those outlined in the case of an existing salt mine. There is some potential for reduction in the ground support hazards, as the excavations can be designed for stability, and entry into disused workings will not be a factor.

Measures to prevent dispersal of waste residues from the surface plant site will be similar to those outlined in Section 3.6; i.e. enclosure of residue storage and transfer areas, and collection and treatment of drainage and washdown water from these areas. In the case of a mine in non-salt

formations, some groundwater seepage into the excavation is expected, as well as minor leakage in the shafts where they pass through aquifers. Mine drainage will be used in the first instance as underground industrial water supply, for dust suppression in materials transfer and rock drilling. Surplus water will be pumped to surface and added to the site drainage collection system. Water which is surplus to the requirements of the site may be treated and disposed of to surface waterways, or alternately injected into a non-potable aquifer beneath the site.

During repository operation ground water flow will be into the repository, and any discharges will be in a controlled fashion through pipelines. After closure of the repository, it is probable that a mine in non-salt formation will be subject to earlier flooding than a salt mine. Mitigation measures are discussed in Section 4.8, Closure and Monitoring.

4.7 SERVICE

As in the case of an existing salt mine, it is proposed that the shaft facilities for waste residue handling be designed to accommodate the projected operating rate on a 40 hour week basis. Underground mining equipment would initially be purchased for the lower excavation and placement and disposal rates of the early years, being increased periodically in line with requirements.

Once the central facilities; i.e. shaft, crusher, and rock disposal facilities are in place, it will be possible to increase the disposal capacity to any level short of the ultimate hoisting limit on 12 to 18 months notice.

The plant will be composed of standard industrial equipment; provided that the physical nature of the materials is adequately defined prior to system design we see no reason for unusual reliability problems. If the repository were to be in a non-salt formation alternate handling systems, such as hydraulic transport, may be feasible. Plant design should be sufficiently flexible to accommodate these options.

As both excavation and waste disposal activities must be carried out, the operation will be more complex than in the case of an existing salt mine where waste disposal activities can be spatially separated from mining. However, with reasonable pre-planning it will be possible to arrange access for both excavation and waste disposal to minimize interferences.

As with any underground facility, operation is essentially independent of surface climatic conditions. Operations remain routine despite surface temperature variations, or heavy rain or snow fall.

4.8 CLOSURE AND MONITORING

Repository sealing procedures will be similar to those outlined for an existing salt mine (see Section 3.8). Procedures will be simpler for the following reasons:

.1 Fewer openings will require sealing, as there will be no pre-existing mine shafts.

.2 Shafts will have been sunk with eventual sealing in mind, so that less final effort will be required.

As previously discussed in the case of an existing salt mine, post-closure monitoring facilities must be installed so as to avoid creating major breaches in the containment envelope. If the repository were in a non-salt (i.e. non-soluble) formation, greater freedom would be permissible in drilling monitoring holes close to the repository formation. These holes could subsequently be sealed using oil well techniques. However, we believe that the shafts will remain the primary avenues of contaminant movement, and at monitoring of water within the shafts will serve as an early warning system.

If the repository were in non-salt formation, a long term containment enhancement would be possible by drilling a deep well into the repository, and pumping out sufficient fluid to create a hydraulic gradient into the repository. Discharge from the repository would thus be under direct control. The pumped solution would be treated for discharge to surface waterways. This technique would not be expected to be necessary, but provides a technically predictable means of improving long term containment.

4.9 COST ESTIMATE

.1 Site Investigation

It is assumed that areas of interest will initially be defined with reference to waste sources, transportation routes, and the availability of surface and subsurface space.

Detailed study of specific areas will concentrate on the deep subsurface, as engineered remedies can be applied to mitigate surface impacts.

Investigations will begin with the assembly of available seismic, well log and regional geologic and tectonic information. Additional surface geophysical work may be commissioned, followed by test drilling and down-the-hole hydrology and geophysics.

Ideally, a program of 12 test holes, with supporting technical work, will suffice. The probable cost is estimated at $2,500,000. A contingency allowance of 100% is required, for a total cost allowance of $5,000,000. No provision is included for senior project administration by OWMC and others, nor for acquisition of surface or subsurface rights.

.2 Capital Costs

Estimates allow for the sinking of materials handling and ventilation shafts to a depth of 600 m for the vertical storage arrangement, or 500 m for a horizontal arrangement.

No allowances are included for permitting procedures, acquisition of surface and subsurface rights, or equipment for transport of excavated rock or solidified waste residues beyond the site boundaries.

The site is assumed to abut an existing highway; no access roads are included.

Summary of Capital Cost Estimate

.1 Vertical Storage Concept

Materials Handling Shaft	$ 8,600,000
Ventilation Shaft	4,900,000
Headframe & Hoisting Facility	8,300,000
Underground Development	4,100,000
Underground Equipment	8,400,000
Change House	540,000
Shaft House	250,000
Shop and Warehouse	500,000
Offices	260,000
Ventilation Intake	250,000
Waste Residue Receiving	1,530,000
Rock Handling - Surface	700,000
Water Treatment	250,000
Sewage Disposal	30,000
Water Supply	150,000
Site Allowances	670,000
Surface Mobile Equipment	550,000
Electrical Substation	250,000
Sub-total	$40,230,000
Design @ 10%	4,020,000
Sub-total	$44,250,000
Contingency @ 10%	4,420,000
ESTIMATED TOTAL CAPITAL COST	$48,670,000

.2 Horizontal Storage Concept

Costs will be similar to those developed for the vertical storage concept, with savings in reduced shaft depth and underground station development.

Adjusted Construction Cost	$38,410,000
Design @ 10%	3,840,000
Sub-total	$42,250,000
Contingency @ 10%	4,230,000
ESTIMATED TOTAL CAPITAL COST	$46,480,000

.3 Operating Cost

.1 Vertical Storage Concept

The estimate assumes that waste disposal will be primarily by gravity discharge from conveyors. Relatively few discharge points will be used each year; conveyor extensions will be done by mine excavation crews as needed.

A credit allowance is indicated for sale of excavated rock for construction use. No costs are included for off-site transportation of excavated material.

Costs are based on operation at design capacity of 134,000 m^3/a.

Summary of Annual Operating Costs

Rock Excavation	$ 2,490,000
Rock Haulage, Crushing & Hoisting	1,020,000
Waste Placement	360,000
Site Service Labour	420,000
Administrative & Technical Staff	600,000
Energy	500,000
Supplies and Services	370,000
Sub total	$ 5,760,000
Credit for Rock Sales	(1,070,000)
Estimated Net Annual Operating Cost	$ 4,690,000

.2 Horizontal Storage Concept

Waste residue disposal techniques will be similar to those proposed in an existing salt mine; i.e. filling of the lower part of the rooms by haulage and mechanical spreading, followed by penumatic stowing for a tight fill.

Summary of Annual Operating Costs

Rock Excavation	$ 3,400,000
Rock Haulage, Crushing & Hoisting	1,100,000
Waste Placement	820,000
Site Service Labour	420,000
Administrative & Technical Staff	600,000
Energy	600,000
Supplies and Services	400,000
Sub total	$ 7,340,000
Credit for Rock Sales	(1,070,000)
Estimated Net Annual Operating Cost	$ 6,270,000

.4 Closure

In either vertical or horizontal repository design, there will be two shafts to be sealed. Allowances have been made in sinking estimates for pregrouting of surrounding formations. Closure work will consist of stripping out shaft furnishings, backfilling, placing of bulkheads, and installation of sampling tubes.

Summary of Annual Operating Costs

Rock Excavation	$ 580,000
Shaft Backfilling (2 shafts)	720,000
Bulkheads (2 shafts, 6 bulkheads)	1,000,000
Monitoring Provisions	200,000
Site Clerance	500,000
Estimated Closure Cost	$ 3,000,000

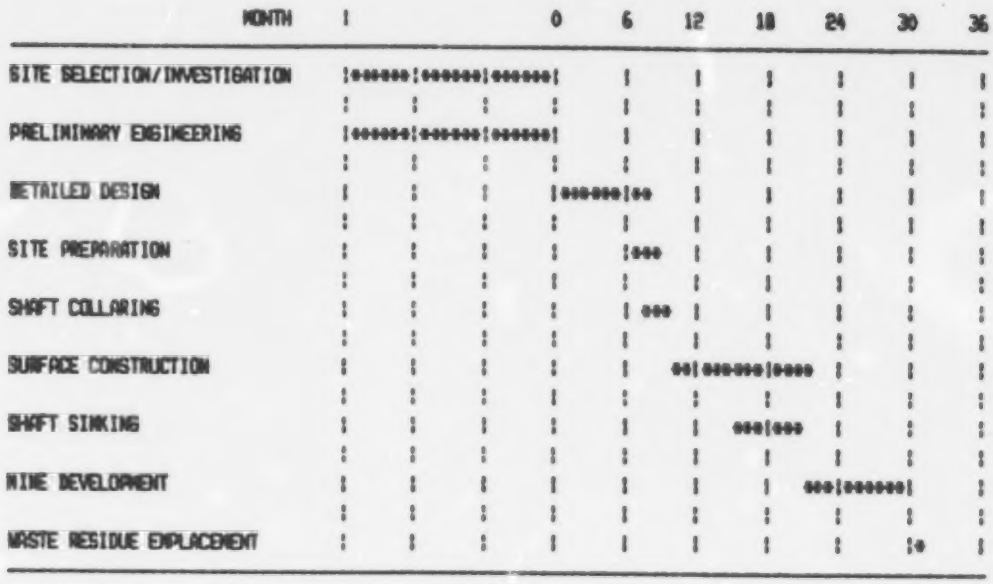
.5 Monitoring

Long term monitoring will be accomplished on a contract basis, periodically sampling groundwater in the shafts.

Allow $50,000/a.

4.10 SCHEDULE

GEOLOGIC WASTE ISOLATION - DISPOSAL IN PURPOSE-DEVELOPED MINE



SECTION 5

SUMMARY AND DISCUSSION

5.1 DISPOSAL IN EXISTING SALT MINES v.s. NEW MINES

Use of existing salt mines for solidified waste residue disposal offers the following advantages:

.1 A substantial amount of information is available, or can be derived by observation, regarding the behaviour of the salt beds and surrounding formations.

.2 Subsurface rights are under the control of a single entity, probably simplifying negotiations for acquisition.

.3 Disposal of mined material does not concern the waste disposal organization.

.4 Capital and operating costs will be lower.

Creation of a new mine as a disposal facility offers the following advantages:

.1 Mine shafts can be located so as to avoid hazards such as surface flooding. Excavation techniques, for instance shaft boring, can be selected to minimize

formation damage during excavation. Pre-grouting of formations can be used to minimize water infiltration during operations, as well as post-closure.

.2 Fewer connections to surface will be required, as there will be no pre-existing mining shafts.

.3 Underground excavations can be designed to enhance ground stability and materials handling.

.4 The facility may be located so as to minimize transportation costs and risk exposure.

5.2 CHOICE OF GEOLOGICAL HOST FORMATION

Selection of a salt formation for creation of a new repository offers the greatest assurance of initially dry conditions. In addition, salt exhibits plastic flow under pressure at depth, and is thus to a large extent self-healing in the event of moderate disturbance by mining or by earthquake. A salt host formation offers the following disadvantages:

.1 The solubility of the salt eliminates the possibility of using hydraulic methods for waste transport and placement. The possibility of using post-closure

pumping to maintain hydraulic gradient into the repository, as discussed in Section 4.8, is significantly restricted.

.2 The repository arrangement is likely to be restricted to a horizontal room system if commercial quality salt is to be produced. If non-commercial quality salt were to be mined, a major secondary disposal problem would result.

.3 Salt remaining in pillars, or in overlying or underlying formations, may be considered a future resource. The presence of stored waste residues would sterilize the adjacent salt reserves.

Non-salt formations include the bedded Paleozoic limestones dolomites and shales, as well as the igneous and metamorphic Precambrian rocks. The Paleozoic formations tend to be homogenous over substantial horizontal distances, with abrupt facies changes occurring vertically. Their geohydrological properties are amenable to analysis by commonly used hydrology models. Shale beds, relatively common in this sequence, are generally of low permeability and may serve as aquitards. Because of the vertical variability of the bedded deposits, repository arrangements may be restricted to a horizontal room and pillar system.

Precambrian rocks are much more variable than bedded deposits, particularly in the horizontal direction. Although the rock types change, the mechanical properties generally remain within a range such that the mass could be considered homogeneous for commercial purposes such as aggregate production. The rocks generally have very low permeability, particularly at depth, with permissivity to hydraulic flow being provided by fracture systems. The prevalence of water in the Precambrian varies greatly. At depth, away from the influence of major faults, the rock may be virtually dry.

Location of a repository in Precambrian rocks, with their favourable mechanical properties, overlaid by thick shales to provide a hydrological barrier, may be attractive.

5.3 REPOSITORY ARRANGEMENT

In a new mine situation the repository arrangement could be in the form of horizontal rooms, or vertical silos. As noted above, the horizontal arrangement may be the only practical choice in bedded deposits where it is required to produce a consistent product for commercial sale. The horizontal arrangement is well adapted to use of rubber tired equipment, including modified surface loaders and trucks.

A vertical arrangement would consist of large caverns or silos over a vertical distance of 50 to 100 metres. The advantages of this approach are:

.1 Less access development is required per unit of storage. This reduces the amount of mine roof exposed, reducing cost and personnel exposure, and reduces transport distances.

.2 The system is suitable for gravity placement of waste material, which is adaptable to a wide range of material characteristics. As the chambers would be of large capacity, only a few disposal points would be utilized in a year, simplifying materials handling.

The disadvantage of the vertical system is in requiring somewhat greater shaft depth.

5.4 RISK

.1 Occupational risks to personnel are estimated to be not greater than those currently prevailing in non-metallic mining activities in the province; i.e. a frequency of not more than [illegible] lost time incidents per 1 million manhours worked. Risk levels would be expected to be decreased by the current activity in development of robotic underground equipment.

.2 Climatic hazards such as dispersal of waste residues from the surface plant site by wind or water are minimized. The surface facilities are limited in extent and since they are of a fixed nature can be enclosed to prevent dust blowing, with drainage provided to collect water.

.3 Seismic effects (earthquakes) are generally less significant underground than in unconsolidated sediments near surface. Facilities should not be located near known fault block boundaries. Surface facilities will be designed to accepted earthquake standards.

.4 Contamination of surface waters will be prevented by collection and treatment of site drainage water. Contamination of aquifers is not a consideration during repository operation as ground water flow will be into the excavations.

.5 Transportation risks arising from waste residue haulage will be that arising from the presence of an additional 25 to 30 large truck trips per day. This could be eliminated by siting the subsurface repository adjacent to the waste solidification plant.

Additional transportation risk may arise from disposal of excavated material, if this material cannot be sold commercially. Where commercial sale is possible, either through use of existing salt mine facilities, replacement of existing salt sales from a new mine, or sale of excavated rock for aggregate or cement feed, no net increase in transportation is considered to result. Increased traffic from the repository would be offset by reduction in traffic from other origins.

5.5 IMPACT

.1 The primary noise source will be the trucks transporting solidified residues and excavated material. Secondary sources will be mine ventilation fans and possibly crushing and screening facilities.

The latter will be contained within fixed structures. The general noise level of the facility is anticipated to be substantially below that of nearby thoroughfares.

.2 The visual impact of the site will be that of a modest size commercial facility, with the shaft headframe rising approximately 50 metres above ground surface. In the case of a new mine there may be stockpiles of excavated material. If necessary, these could be replaced by bins to modify the visual impact and avoid any dusting problems.

.3 Small amounts of blasting smoke will be emitted daily, with each emission lasting 15 to 20 minutes. The smoke will have a light odour, and will dissipate over a few hundred yards.

During some seasons of the year, ventilation air upcasting from the mine will condense water vapour, which will result in a visible plume. This plume will be of high transparency and will dissipate rapidly except on days of very high humidity.

.4 The principal dust sources will be from truck traffic and possibly from handling of excavated rock. Dust originating from crushing and screening operations on surface will be confined within fixed structures, and collected. The greatest dust problems are anticipated during construction; once site paving is completed a high level of housekeeping will be expected, with minimal dust generation.

.5 A facility will provide from 30 to 65 jobs in the local economy, depending on the type of facility chosen. This employment will be of a stable long term nature, with a high percentage of trades and administrative personnel. These figures do not include personnel required to deliver waste residues to the site, transport excavated material to sale or disposal, or local suppliers and tradesmen.

.6 A surface land area of 4 hectares is estimated for the disposal site adjacent to an existing salt mine, or 6.5 hectares for a new disposal facility. This surface area could potentially service a subsurface repository in excess of 1,000 hectares, with a life of several decades.

5.6 SERVICE

.1 Flexibility

Ultimate disposal capacity is dependent on generous sizing of shaft hoisting facilities at initial design. Underground excavation/disposal rates can be modified readily by adding men and equipment. Major changes in capacity should be made with at least 12 months lead time so as to allow the necessary excavations to be prepared, in the case of a new mine facility. In the case of storage in an existing salt mine where available volumes are essentially unlimited, capacity could be increased on shorter notice.

.2 Reliability

The geotechnical reliability of the repository; i.e. ground support and dewatering, are dependent on siting of the repository within suitable formations. Local-

ized problems, such as presence of a fracture zone, which may not be detectable in preliminary siting investigations, can be mitigated during operation by grouting and/or re-orientation of underground excavations.

The mechanical and electrical components used in the operation will be of standard designs and no unusual reliability problems are anticipated because of the nature of the material handled.

It is not anticipated that active containment systems will be required after closure of the repository. Hydraulic gradients, and thus groundwater velocities, are very small at depth. The repository will be sited so as to have substantial aquitards between surface and repository level, and all access openings will be carefully sealed. Substantial experience is currently available in bulkheading and grouting of underground openings, and further related knowledge is under development in the nuclear waste storage field.

Geohydrological knowledge gained during operation of the repository will be of value in planning a long term monitoring program. It is expected that the shaft openings will in all cases be the most significant breeches of the geological envelope, even with the best

sealing techniques available. Monitoring will be concentrated in the shafts, above the concrete plugs. Shafts will be totally backfilled with a mixture of granular material and bentonite, to provide long term structural support, to provide sealing additional to the concrete plugs, and to provide ion absorption for possible contaminants solutions.

5.7 PERFORMANCE

No manmade system has demonstrated containment performance beyond a few decades. Natural geologic systems have demonstrated containment of gases and fluids over several millions of years. Similar performance can be expected of these formations when utilized to isolate a manmade repository. The greatest weakness in the isolation system is likely to be the access openings. These openings offer perhaps the best possible setting for construction of high quality seals, providing a structurally competent environment and areas of low permeability.

A deep subsurface repository will be impervious to the effects of wind, rain, earthquake, and glacier. It must be remembered that Southern Ontario has been glaciated several times, most recently only 10,000 years ago.

5.8 COSTS

Cost estimates are summarized on Table 1. Creation of a new mine for waste residue disposal is more expensive in capital and operating costs than use of an existing salt mine.

TABLE 1

GEOLOGIC WASTE ISOLATION - SUMMARY OF COST ESTIMATES

	Existing Salt Mine	New Mine	
		Vertical Layout	Horizontal Layout
Capital Costs			
Site Investigation	$ 2,500,000	$ 5,000,000	$ 5,000,000
Construction	22,470,000	40,230,000	38,410,000
Engineering	2,250,000	4,020,000	3,840,000
Contingency	2,470,000	4,420,000	4,230,000
Subtotal Construction	$27,190,000	$48,670,000	$46,480,000
Cost to Initial Disposal	$29,690,000	$53,670,000	$51,480,000
Annual Operating Costs[1]			
Mine Excavation Changes	1,340,000	---	---
Excavation	---	4,880,000	6,120,000
Disposal	2,630,000	880,000	1,220,000[2]
Credit for Rock Sales	---	(1,070,000)	(1,070,000)
Net Annual Operating Cost	$ 3,970,000	$ 4,690,000	$ 6,270,000
Closure Costs	$ 9,000,000[3]	$ 3,000,000	$ 3,000,000
Annual Monitoring Costs	$ 50,000	$ 50,000	50,000

1. At full rated capacity - 134,000 m^3/a.
2. Reduced disposal cost vs. salt mine reflects elimination of rehabilitation work and assignment of overheads to excavation.
3. High cost reflects effort to seal pre-existing mine shafts.

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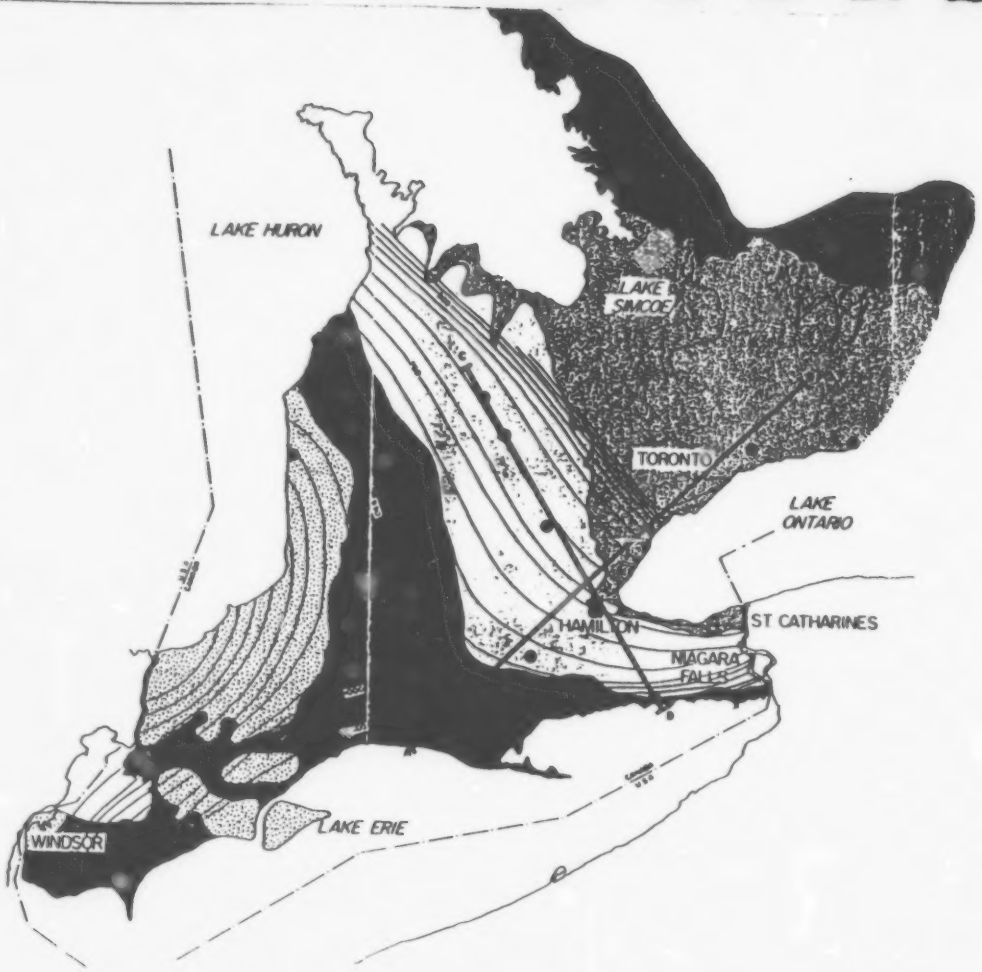


LEGEND

PRECAMBRIAN SURFACE DEPTH

LINE OF CROSS-SECTION

DRILL HOLE

AREA UNDERLAIN BY SALT

SUBOUTCROPS

PRECAMBRIAN

ORDOVICIAN

SILURIAN

DEVONIAN

GEOLOGICAL COMPOSITE MAP OF SOUTHERN ONTARIO

OWMC - M M DILLON CO WASTE ISOLATION STUDY

07-171-01

1

M COOK CO LIMITED

LEGEND

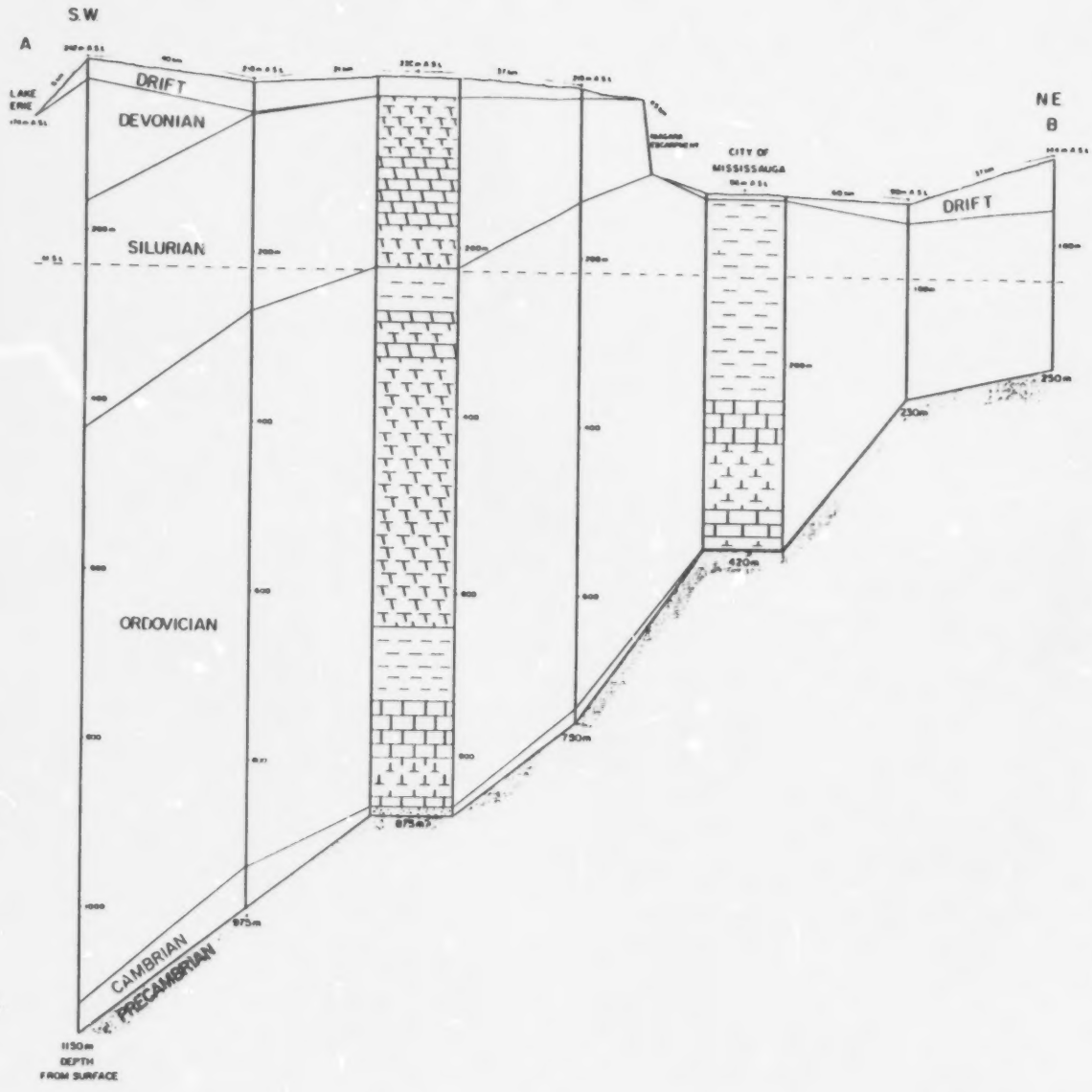
- OIL FIELDS
- GAS FIELDS

OIL AND GAS FIELDS IN SOUTHERN ONTARIO

OWMC - M M DILLON CO
WASTE ISOLATION STUDY

PROJ NO
87-171-01
DWG NO
2

G G COOK CO LIMITED
CONSULTING ENGINEERS



LEGEND

- DOLOMITE
- DOLOMITIC SHALE
- SHALE
- LIMESTONE
- LIMY SHALE
- SANDSTONE

VERTICAL SCALE

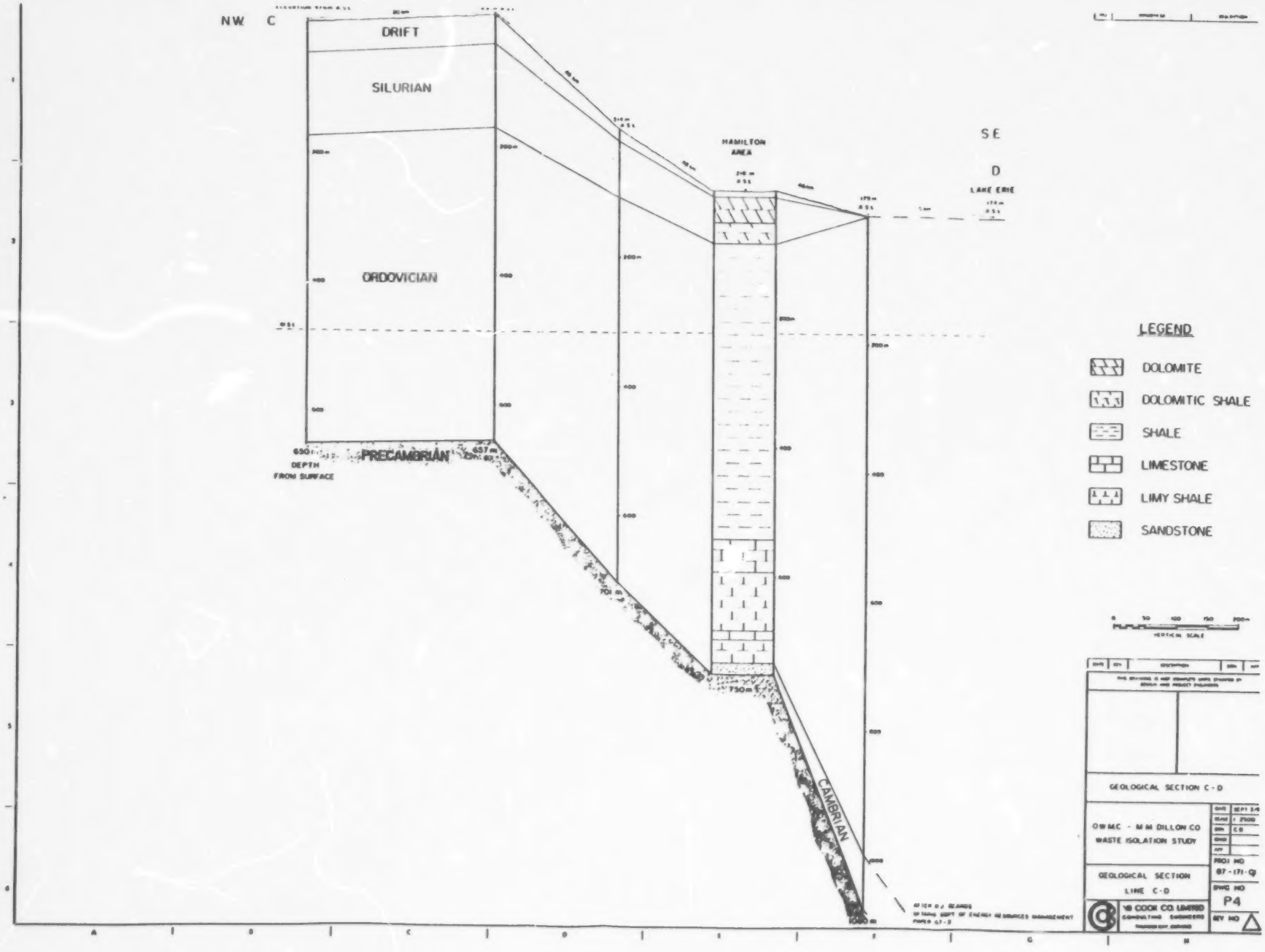
GEOLOGICAL SECTION A-B

OWMC - MM DILLON CO
WASTE ISOLATION STUDY

GEOLOGICAL SECTION
LINE A-B

V.B COOK CO LIMITED
CONSULTING ENGINEERS

PROJ NO 87-171-01
DWG NO P3
REV NO


NW
C
DRIFT
SILURIAN
ORDOVICIAN
PRECAMBRIAN
DEPTH FROM SURFACE
HAMILTON AREA
SE
D
LAKE ERIE
CAMBRIAN
LEGEND
DOLOMITE
DOLOMITIC SHALE
SHALE
LIMESTONE
LIMY SHALE
SANDSTONE
GEOLOGICAL SECTION C - D
OWMC - M M DILLON CO
WASTE ISOLATION STUDY
GEOLOGICAL SECTION
LINE C-D
W GOLDER CO LIMITED
PROJ NO
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DWG NO
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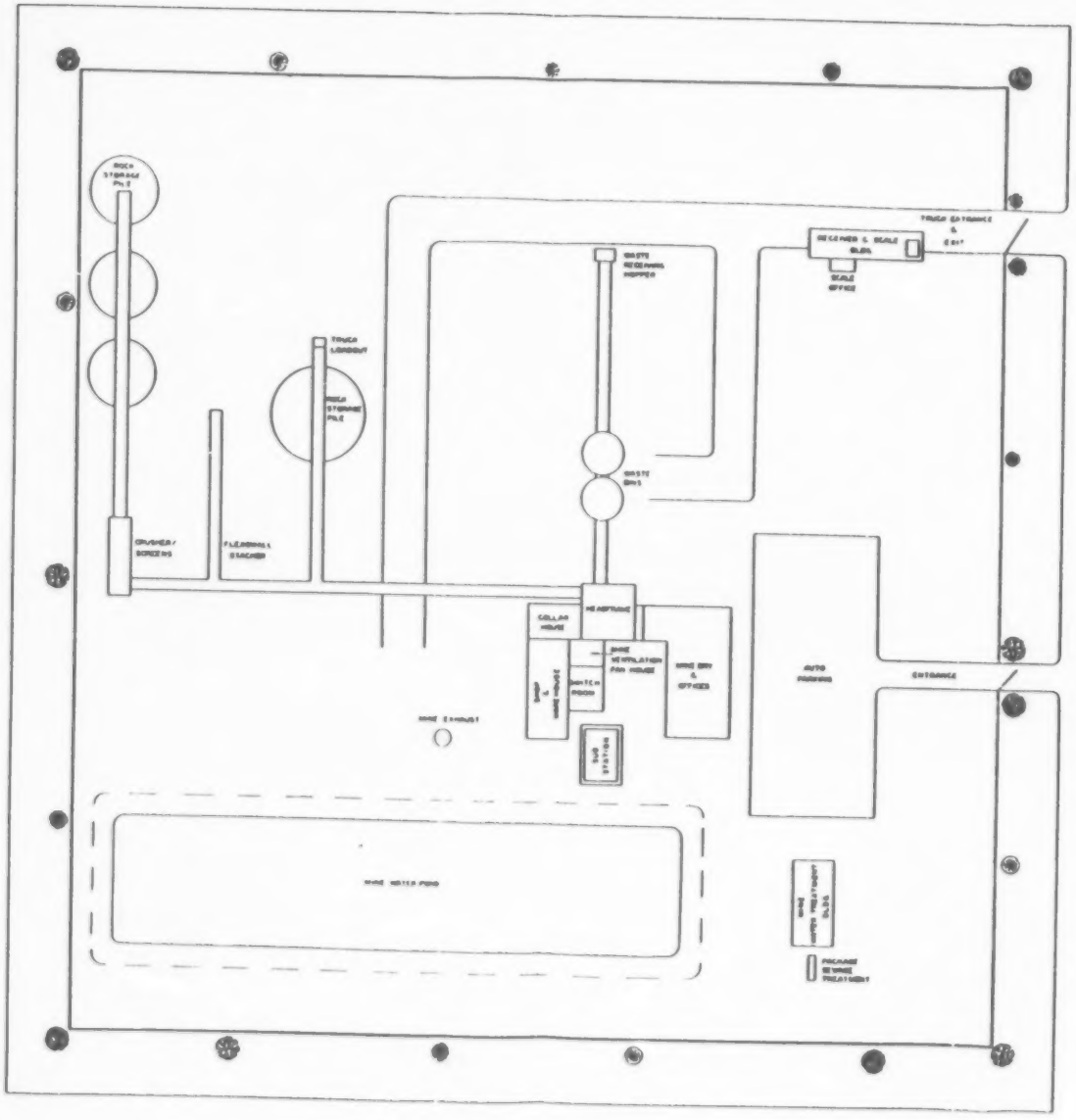
REV NO



SITE PLAN
MINED WASTE STORAGE

OWMC - M M DILLON CO
WASTE ISOLATION STUDY

DATE	SEPT 5-0
SCALE	1:500
DRN	C.G
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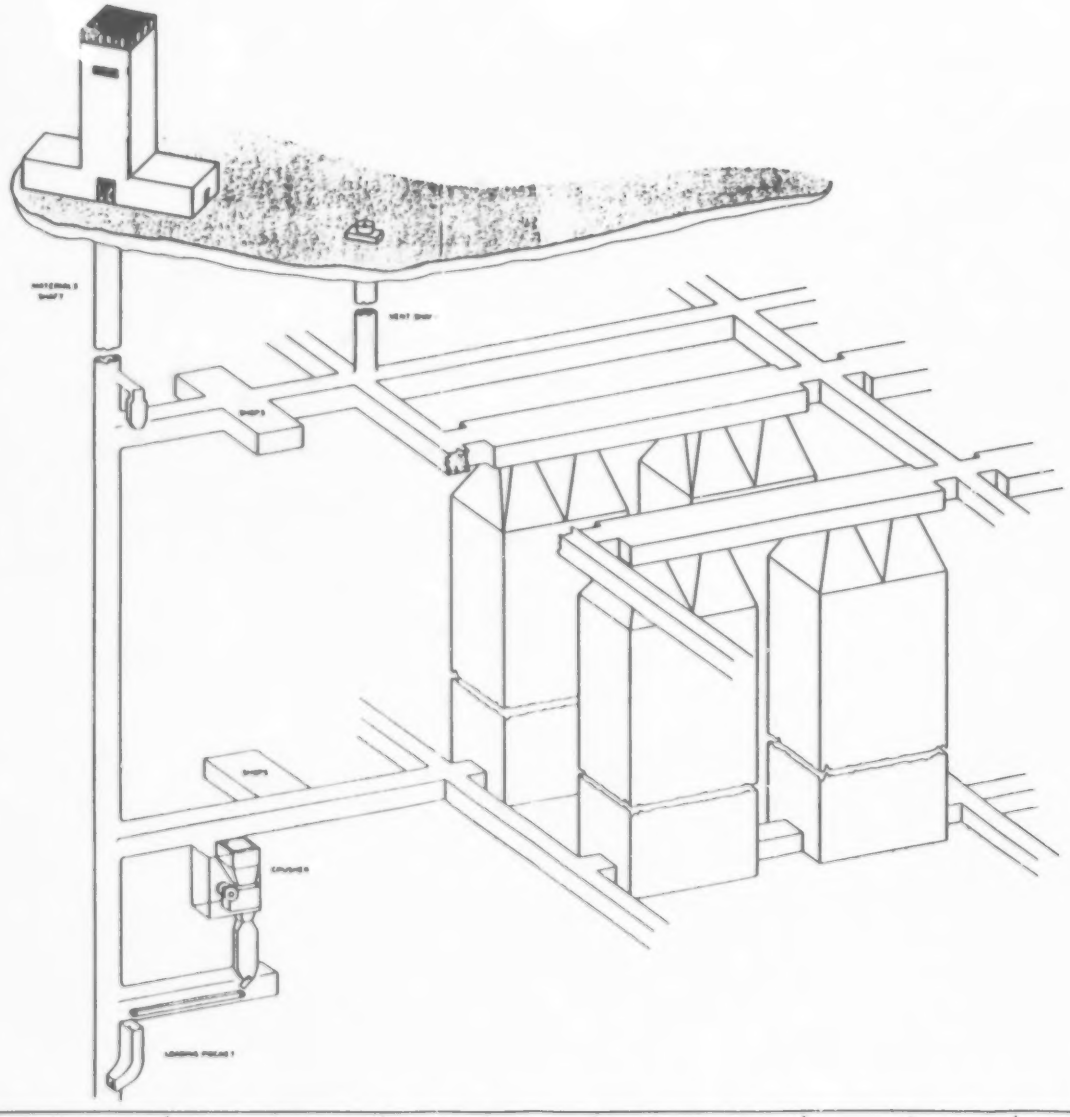
W. COOK CO. LIMITED
CONSULTING ENGINEERS



MINED WASTE STORAGE
VERTICAL LAYOUT

OWMC - M.M. DILLON CO
WASTE ISOLATION STUDY

M. M. DILLON LIMITED
CONSULTING ENGINEERS

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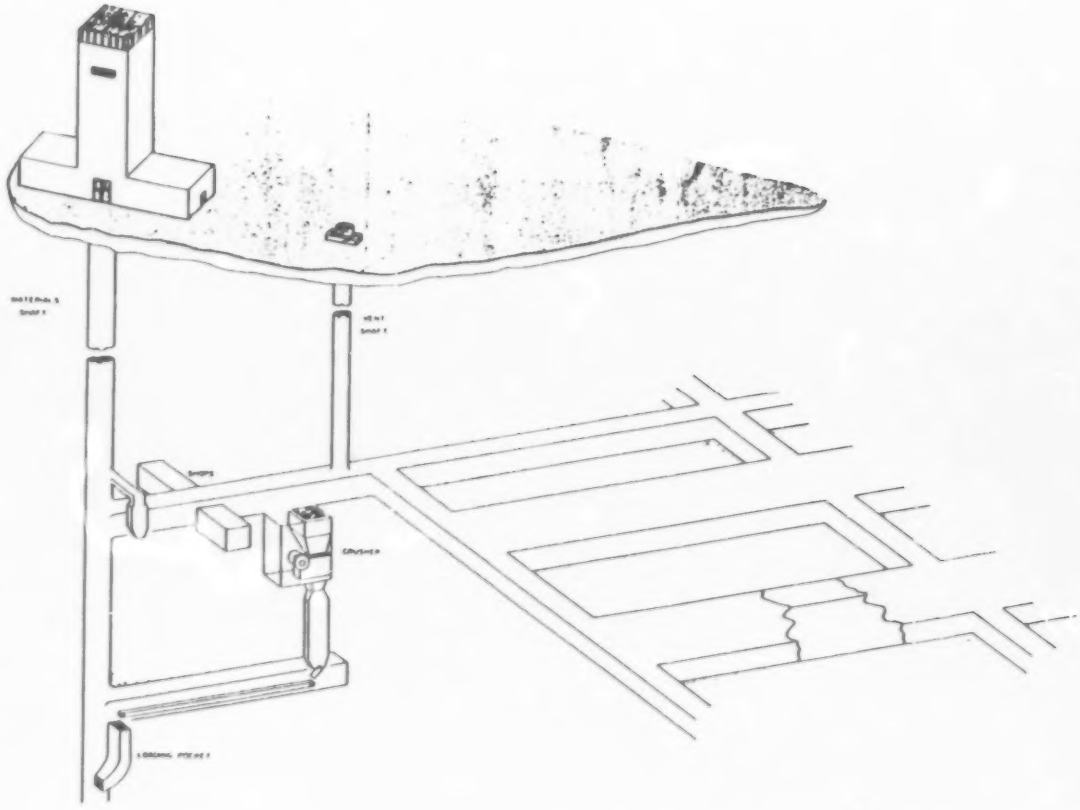

MINED WASTE STORAGE
HORIZONTAL LAYOUT

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WASTE ISOLATION STUDY

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W COOK CO LIMITED
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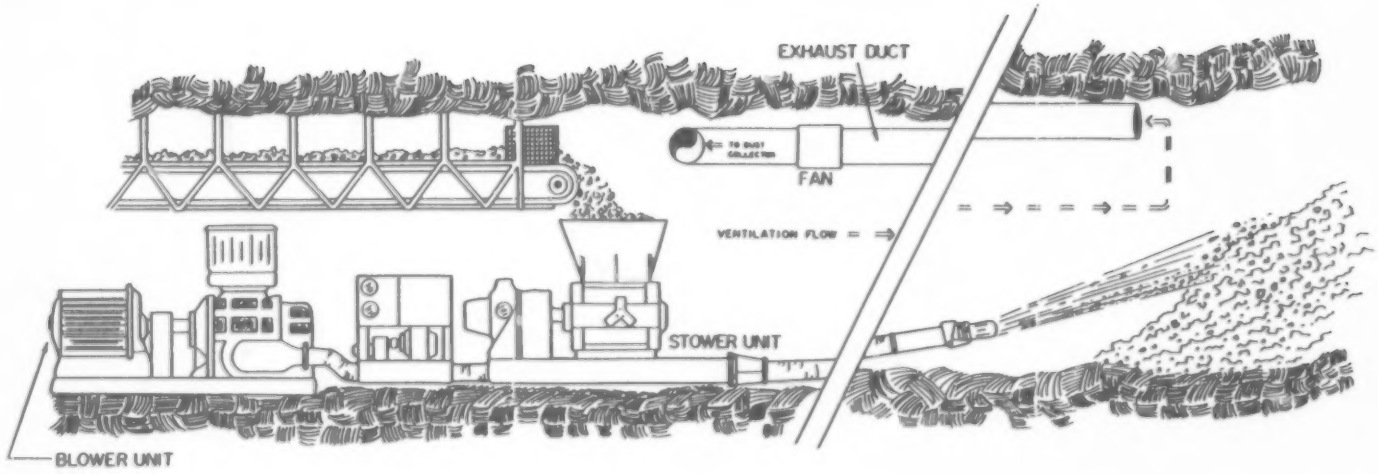
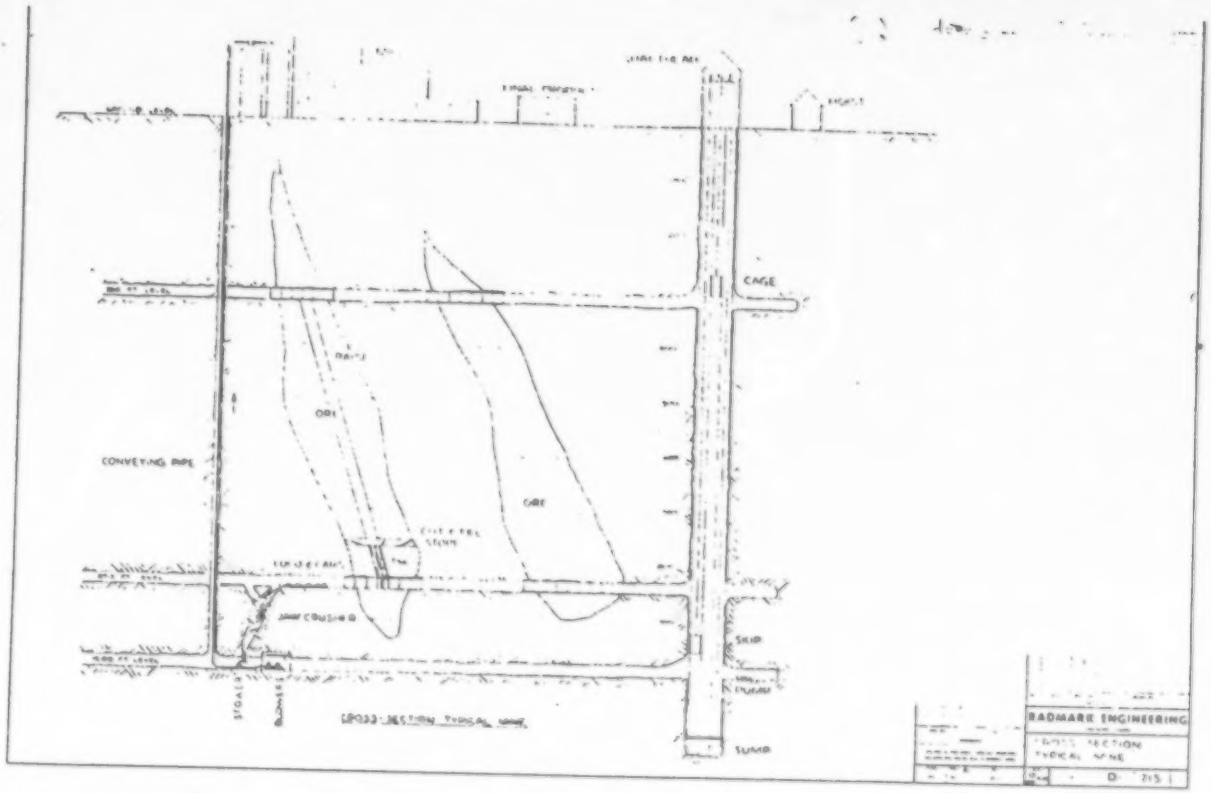


PNEUMATIC STOWAGE OPERATING CONCEPT

OWN C - M M GILLON CO
WASTE ISOLATION STUDY

YB COOK CO LIMITED

DWG NO 8



PNEUMATIC BACKFILLING

By D. G. Ball, P.Eng.
General Manager, Radmark Engineering Limited

The principles of pneumatics have fascinated engineers since the early days of the industrial revolution. Pneumatic conveying systems were in effective use before the turn of the century. The chemical, food and wood products industries were the first to introduce extensive systems into their operations. Some 25 years ago European coal mines started using pneumatic systems in their underground operations for backfilling. Broken shales were conveyed several thousand feet below ground before placement. The success of this development and the resulting economies prompted further extension into the field of hard-rock mining and tunnelling.

On this continent, a large Canadian mining company and a firm of pneumatic conveying specialists joined forces to develop equipment robust enough to meet the requirements of hard rock stowing. The main problem facing the research team was the high abrasion factor of igneous rock. Extensive experiments with numerous metals and machine components were conducted; three successive prototypes were tested underground. At the end of the third development stage abrasion resistant characteristics were such that economic operation was assured — hard-rock pneumatic backfilling had become a reality.

The equipment now available can convey −3-in. igneous rock with capacities of up to 300 tons per hour. The flexibility of pneumatic systems with the ability to convey horizontally, vertically and around bends makes it a desirable tool for underground operations where material handling systems need to be compact and portable.

The productivity of an underground operation can be increased in three main areas:

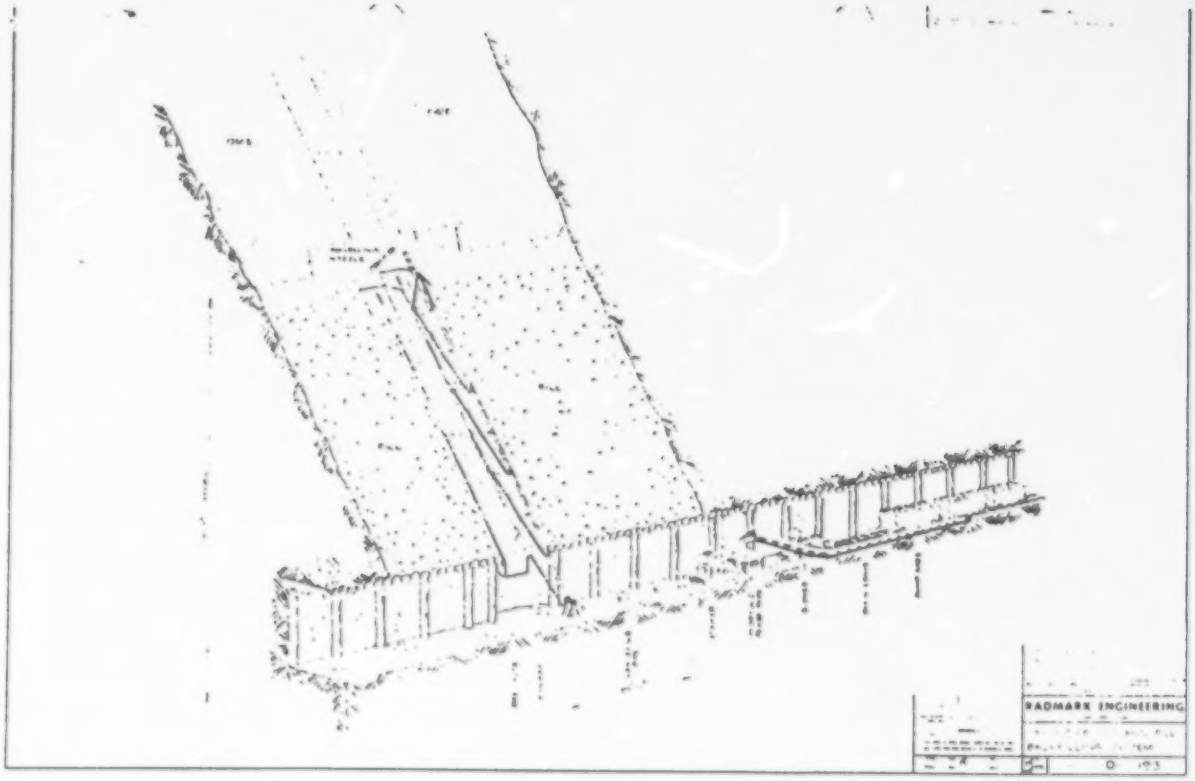
1. Backfilling
2. Excavating
3. Hoisting

Advantages of pneumatic stowing

1. **The fill material is placed with optimum moisture content, which can be controlled for maximum consolidation.**
2. **Pneumatic stowing can completely fill areas that cannot be filled by any other means.**

D. G. Ball, P.Eng.

The author was born in South Wales, Great Britain, in 1935 and was educated at the South Wales College of Advanced Technology, University of Wales. He graduated with the degree of mechanical engineer in 1958, mining engineer in 1960, and electrical engineer in 1961. Before coming to Canada he held positions of unit mechanical engineer and area reconstruction engineer with the British National Coal Board. Prior to joining Radmark Engineering Limited, Mr. Ball served as senior mechanical engineer for the consulting and design engineering firm of Wright Engineers Limited, Vancouver.



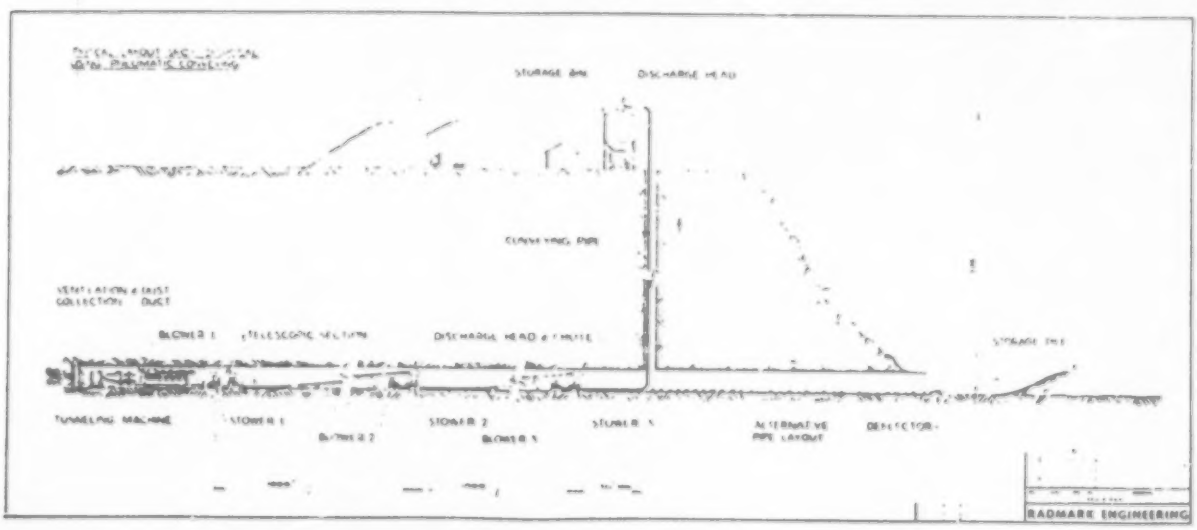
3. Because the ground is supported by a structural fill, a greater volume of ore may be extracted.
4. Large particle sizes (−3-in.) may be accommodated and, in many cases, only grizzly screening ahead of the stowing machine will be necessary.
5. Current costs are compatible with other backfilling methods.

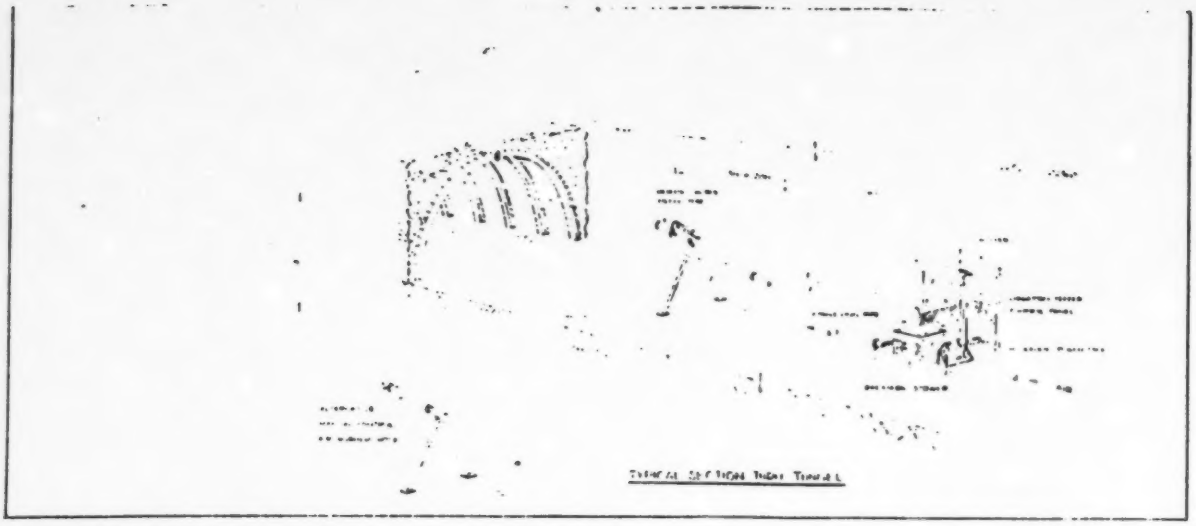
The application of pneumatic systems become most advantageous when filling has to be accomplished in difficult areas and where good roof support is of paramount importance to the extraction of the ore body.

Description of a pneumatic conveying system

A pneumatic conveyor system consists of three main parts:

1. A positive displacement blower to supply the required air volume. To move material through a pipeline a sufficient velocity of conveying air must be maintained to keep the particles in suspension. The operating pressure of a system increases with: (a) the length of pipeline employed, (b) the number of bends, (c) the vertical distance of lift, (d) the frictional characteristics of the material conveyed, and (e) the volume of material being transported.
2. The stowing machine or feeder unit. Here the material drops through a rotary chamber type airlock into the conveying pipeline. The rotating airlock stowing machine is the one in most general use in Europe and is the most advantageous in hard-rock applications. The feedwheel rotates in a fixed housing, the top of which is open to the atmosphere for the introduction of the backfill material. The lower part is chambered to accept the





material and forms part of the pipeline. The feedwheel and the sidejaws are adjustable to compensate for wear.

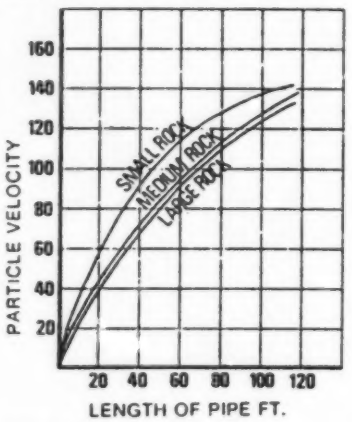
3. **The pipeline. Present Radmark systems can accommodate up to a thousand feet of pipeline achieving vertical lift of up to 500 ft. The pipe commonly used is of two layer construction; the inner layer being extremely hard, in the order of 650 to 700 Brinell, while the outer layer is of mild steel. A deflector at the end of the pipeline makes accurate placement possible.**

The description of the system may be simplified by comparing it to a large automatically fed blowgun. The length of the pipe determines velocity and the resulting impact of the material ejected achieves the high compaction of the placed fill.

The scope of this article restricts a detailed discussion of the technical specifications. However, the following graphs and comparisons, together with some of the parameters, illustrate the versatility of pneumatic systems.

Graph 1:

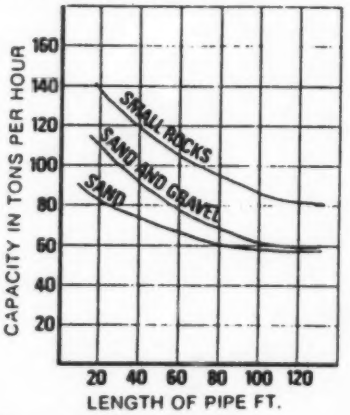
This graph illustrates the power needed to convey different materials through the same length of pipe. Smaller particles require less power; larger particles need more power. The ideal fill, which contains a full range of particle sizes, falls midway between.



Graph 2:

The velocity of the conveyed particles depends on the length of pipe employed. The longer the pipe, the greater the velocity. However, approximately 80% of the maximum particle velocity is achieved in the first 40 feet of pipe. There is a definite relationship between particle size and acceleration distance. Large particles accelerate at a slower rate than small particles, therefore, large particles require a longer distance to reach conveying velocity. A minimum of 30 ft. of pipeline is required to achieve a well consolidated fill. The degree of compaction is determined by discharge velocity. If the material is passed around a bend in the pipeline, at least 15 ft. of pipe is required to compensate for the resulting friction losses.

High velocity is only required to achieve the compaction need for backfilling. Systems used exclusively for transport are designed to operate at slower speeds to benefit from the reduced abrasion.

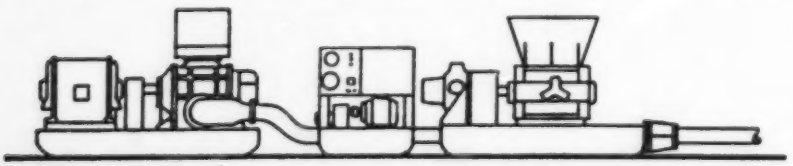


Compaction of fill

The investigation of pneumatically placed materials revealed compaction and complete filling against the hanging wall. Tests on the in-place density indicated 140 lb/cu. ft. or approximately 80% of solid rock. Further tests have confirmed this high compaction. Work is presently carried out by the United States Bureau of Mines to fully analyse the advantages of this aspect.

Economics of system operation

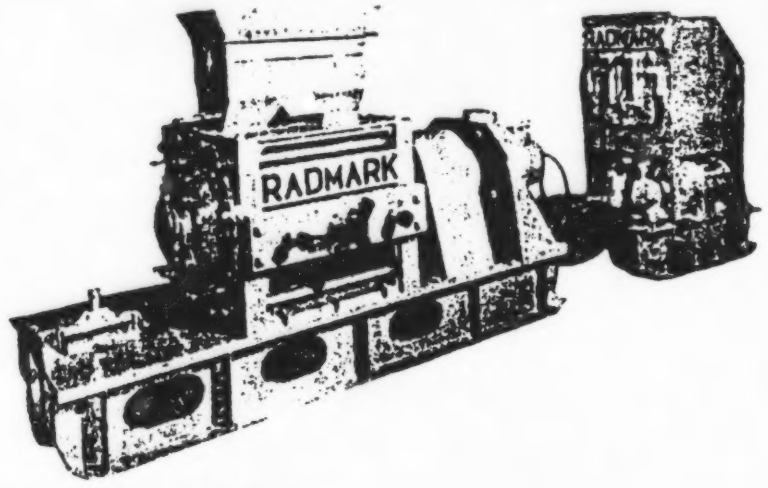
The following results were compiled during the third phase of the development. In this test the sys-



tem operated for 200 hours handling 17,500 tons of material. The material handled was primarily argillite, the product of a float-sink operation with the rock being previously crushed to ---3-in. The complete operating costs of that system are shown as follows:

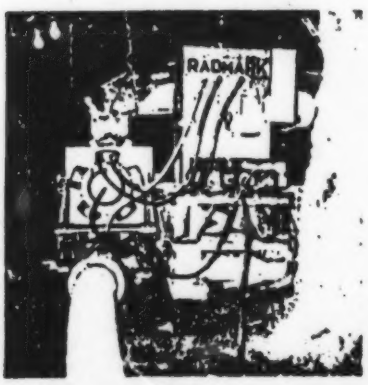
Operating costs of Phase III development	**¢/ton**
Rebuilding costs — Rotor tips & side jaws	8.75
Maintenance costs	3.80
Pipe replacement — Labor & power	8.00
Operating costs of pneumatic placement	**26.35¢/ton**
Depreciation — Blower	2.50
— Stower	3.25
Total owning and operating costs	32.10¢/ton

The system is still working on a two-shift basis. Operating costs are now between 20 and 22¢ per ton of material placed.



Pneumatic excavating

Interesting examples of pneumatic conveying are the systems presently used to convey wood chips. Here, capacities of up to 500 tons per hour and distances of up to one mile are achieved. To convey broken rock and sand by the same method requires only a reduction of the parameters and equipment adapted to the higher abrasion factor. The equipment presently available is capable of up to 300 tons per hour through 1,000 feet of pipeline. Present research indicates that the length of pipeline can be extended to over 4,000 feet in the future.

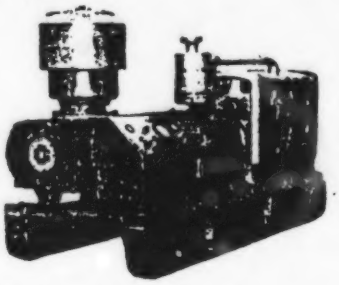


Radmark Stower underground at Canadian mining operation–Opening is 8' x 8'.

Pneumatic systems are ideally suited to remove the spoil from tunnel boring machines. Studies have indicated that more than 85% of the boring machine product is directly acceptable to a pneumatic system. The pneumatic conveyor is attached to the rear of the tunnelling machine. A section of telescopic pipe allows the machine to move ahead on a continuous basis.

The spoil is conveyed through the pipeline and if necessary is discharged directly into the infeed of a second system, until it is delivered to the surface or the tunnel portal. Any significant quantities of oversize material can be passed through a small crusher. An interesting feature of this application is the system's ability to ventilate the tunnel and to extract dust from the driving head.

The equipment is robust and compact. The main dimensions of the system are approximately 3 ft. by 4 ft. by 9 ft. The diameter of the pipeline varies according to capacity. A 300-ton-per-hour system would require a pipe diameter of 14 in. The system can discharge either into truck bins or onto waste piles. Tunneling under built up areas where surface access is limited is an ideal application for a pneumatic system. The spoil can be lifted vertically through a bore hole and discharged directly onto a truck-bin.



Blower unit

The operating costs of pneumatic excavating, particularly behind a tunnel boring machine are considerably lower than the operating costs of a conventional mucking system. A recent study of mucking systems compared the cost of a 200-ton-per-hour, 5,200-ft. pneumatic system with conventional rail mucking. The pneumatic system operated for $2.10 per yard, while the conventonal method cost $4.60 per yard.

Pneumatic hoisting

A pneumatic conveyor can be used where material has to be hoisted. The present limitations of a vertical system are 500 ft. in a single lift. Greater lifts can be accomplished by placing several systems in series with the final system discharging into a bin. Primary crushing below ground is required for feeds of over 3 in.

Sketch No. 2 shows a layout of a small mine using a pneumatic hoisting system. One of the shafts is a conventional shaft for general access of men and materials to the mine, the second shaft is a raise-bored 72-in.-diameter shaft which would house the pneumatic conveying line and a man-way. This pipeline is lowered down the shaft and clamped to the wall. The main blowers are located at the bottom of the shaft to assist with the ventilation of the mine. Material is conveyed from the crushing station and then vertically up the shaft. The bend at the bottom of the shaft is readily serviceable.

The capital cost of developing

Stowed material projected 150' away from pipeline.

and equipping a mine such as this is considerably less than that of a conventional two shaft mine because:

1. **The much lower cost to raise bore a 72-in. diameter shaft than to sink a conventional shaft. A recent investigation indicated a difference of 600% in these costs.**
2. **The capital cost of the equipment, i.e. hoisting gear and skips to a pneumatic conveying system also represents approximately 200% savings.**
3. **The installation of the hoisting equipment is many times that of the vertical pipeline.**

The estimated operating costs of such a pneumatic system handling 200 tons per hour are:

	Operating Costs
Power	5.6¢/ton
Labor	8.0¢/ton
Pipe	4.5¢/ton
Refurbishing	5.0¢/ton
Maintenance	4.0¢/ton
Depreciation	2.5¢/ton
	29.6¢/ton hoisted

Summary

Pneumatic conveying of —3-in. rock up to 300 tons per hour is now a reality, both above and below ground. The main applications below ground are backfilling, excavating, and hoisting. Backfilling applications are already in operation, and work is presently being carried out on both excavating and hoisting systems. A pneumatic conveyor used below ground has the desired flexibility and compactness required in an underground operation. The economics of pneumatic conveying below ground from both the capital and operating aspects show considerable savings over conventional material handling systems.

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RADMARK ENGINEERING LIMITED

RADER

Rader Canada Ltée/Ltd
C.P./P.O. Box 925,
Saint-Laurent, Québec H4L 4W3
(514) 331-1200 Télex: 05-824609